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# STUDIES ON TRAINING GROUND OBSERVERS TO ESTIMATE RANGE TO AERIAL TARGETS

Michael R. McCluskey, et al

George Washington University
Alexandria, Virginia

May 1968

Technical Report 68-5



# Studies on Training Ground Observers to Estimate Range to Aerial Targets

by

*Michael R. McCluskey, A.D. Wright, and E.W. Frederickson*

HumRRO Division No. 5 (Air Defense)

May 1968

Prepared for:

Office, Chief of Research and Development Department of the Army

Contract DA 44-188-ARO-2



HumRRO

The George Washington University
HUMAN RESOURCES RESEARCH OFFICE

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1. This report describes a series of studies dealing with methods for training observers in range estimation performance. The research is part of a continuing effort to improve individual training and performance in aerial target detection.

2. Six experiments were conducted. The specific purposes of the research were to determine the effects of training on performance, identify some of the factors that influence range estimation, and determine the effectiveness of miniaturizing the training environment. Several variations of range estimation training methods were studied, but the basis for all techniques was either immediate knowledge of results after making an estimation, "paired associate" presentation of aircraft position with true slant range, or the use of an occluding object as a range estimation aid. The research data were obtained by field testing at Fort Bliss, Texas.

3. This report should be of value to personnel responsible for training in range estimation and aerial target detection, and to those interested in training methods and techniques.

FOR THE CHIEF OF RESEARCH AND DEVELOPMENT:

Charles E. Ramsburg

CHARLES E. RAMSBURG
Lieutenant Colonel, GS
Chief, Behavioral
Sciences Division

## FOREWORD

In December 1964 the Combat Developments Command, Air Defense Agency, recommended that HumRRO begin research in "the areas of visual surveillance, detection, identification, and range estimation in support of military studies of the effectiveness, doctrine, manpower requirements, and training for visually sighted air defense weapons." In support of this research requirement and related requirements from U.S. Continental Army Command, HumRRO Division No. 5 (Air Defense) started an intensive program of studies on these problems in late FY 1965, as Exploratory Study 44. These studies of visual and auditory skills were continued during FY 1966 as HumRRO Work Unit SKYFIRE, Training Methods for Forward Area Air Defense Weapons.

The studies described in this report were either pilot studies for SKYFIRE Sub-Unit I or consulting requests from the Army. These studies were completed by HumRRO Division No. 5 under Dr. Robert D. Baldwin, Director of Research, during the spring and summer of 1966. The entire engineering staff of the U.S. Army Air Defense Human Research Unit and all of the Unit enlisted men assisted in various phases of the research efforts.

MAJ A.D. Bell, Chief of the Human Research Unit, served as military test officer and coordinated military and civilian activities. For the majority of the studies, the U.S. Army Air Defense Center provided military observers, range facilities, and Army aircraft. High-performance aircraft were furnished by the Twelfth Air Force support group at Holloman Air Force Base, New Mexico.

HumRRO research for the Department of the Army is conducted under Contract DA 44-188-ARO-2 and Army Project 2J024701A712 01, Training, Motivation, Leadership Research.

Meredith P. Crawford
Director
Human Resources Research Office

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HumRRO Division No. 5 (Air Defense)
Fort Bliss, Texas
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HUMAN RESOURCES RESEARCH OFFICE

Technical Report 68-5
Work Unit SKYFIRE
Sub-Unit I

The Human Resources Research Office is a nongovernmental agency of The George Washington University. The research reported in this Technical Report was conducted under contract with the Department of the Army (DA 44-188-ARO-2). HumRRO's mission for the Department of the Army is to conduct research in the fields of training, motivation, and leadership.



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## Military Problem

The forward area gunner equipped with small arms, larger caliber automatic weapons, and missile systems is now being considered capable of an air defense role. One of the perceptual skills required for this role is the accurate estimation of the weapon's effective range. Corrrect range estimation will conserve ammunition, increase the number of potentially effective rounds fired, and increase the probability of taking the proper lead.

## Research Problem

The ability to estimate range to ground targets has been fairly well documented, but range estimation performance with aerial targets has received only minor study. The possibility of training range estimation skills and the study of variables that may affect performance have been relatively unexplored. Six pilot studies were conducted to determine the effects of training on range estimation performance and to identify some of the relevant variables.

## Method and Results

### Experiment I

The purpose of the first experiment was to conduct an initial study of range estimation training methods, and determine whether range estimation skills could be trained. Sixteen Army personnel serving as subjects for the experiment were randomly assigned to one of four treatment groups: "immediate reinforcement" training, in which trainees were given immediate knowledge of the true range after making an estimation; "paired associate" training, in which the true range information was provided while the aircraft was being observed; "finger occlusion" training, in which the index finger was used as a range estimation aid; or the control group.

All subjects received 6 pretest trials, 18 training trials, and 6 posttest trials. On all test trials their task was to estimate a range of 350 meters, but during training the response varied according to the training method employed. The test aircraft was a U-6A which flew a constant speed of 100 knots at altitudes of 175, 300, and 400 feet and crossing ranges of about 90, 150, and 200 meters.

The results indicated that there were no significant differences between the training methods. The difference between pretest and posttest performance was significant, so it was concluded that the overall training was effective in teaching range estimation skills. A significant difference was also found between incoming and outgoing range estimation errors.

### Experiment II

This study explored the effects of aircraft elevation and the amount of illumination on range estimation performance. The subjects, aircraft, aircraft speed, and test site were the same as those used in Experiment I. To test the aircraft elevation hypothesis, the aircraft was required to fly at two widely separated altitudes—75 and 400 feet; these altitudes produced target elevations of 9° and 55°. The amount of illumination was varied by requiring the subjects to wear variable-density goggles. The subjects were required to estimate a range of 350 meters twice for each aircraft pass—once incoming and once outgoing—for a total of 20 passes.

It was found that aircraft elevation had a significant effect on range estimation performance, but variations in the amount of illumination had no significant influence. Low aircraft elevation may have produced larger apparent aircraft size, resulting in overestimation of range, but the overestimation was significantly reduced at high elevation.[1] The difference between incoming and outgoing estimation errors proved to be significant.

## Experiment III

The objective of the third study was to determine an acceptable method of training range estimation for the ranges of 400, 800, 1,500, and 2,500 meters. An F-100 jet aircraft and an H-23 helicopter served as the test aircraft. The F-100 maintained a constant speed of 400 knots, and both aircraft flew overhead and 200-meter offset courses at altitudes of 250 and 750 feet.

Twenty-eight Army personnel were randomly assigned to one of four range estimation training methods based on two of the methods used in Experiment I. In addition, one-half of the subjects received supplementary training utilizing a helicopter to provide a stationary target for learning distances. The training methods tested were (a) immediate reinforcement, (b) immediate reinforcement and helicopter, (c) paired associate, and (d) paired associate and helicopter. The observers received 36 training trials each day for the three-day test period. A 12-trial pretest was given initially and posttests of 12 trials were administered at the end of each training session.

After a qualitative inspection of the data, immediate reinforcement training was selected as the best available. The data collected for this group were then used in additional analyses. The difference between incoming and outgoing estimation errors was found to be significantly reduced with additional training, and was practically eliminated with 108 training trials. Estimating range to a high-speed jet aircraft appeared to result in increased underestimation for the outgoing direction of flight.

## Experiment IV

This study was aimed at determining the relative efficiency of reduced-scale vs. field range estimation training. Six Army personnel served as observers for the test. They received reduced-scale training and field testing in conjunction with Experiment III. The training was conducted with a 1:50-scale F-100, which was viewed at scale ranges. The observers walked to the scale range of interest, and were told it was equivalent to X meters range. They were trained with the paired associate method for a total of 36 trials and tested in the field along with the subjects participating in Experiment III.

The results indicated that the reduced-scale training technique was as good as, or better than, field training for the outgoing range estimates, but significantly inferior to field training for incoming range estimates. Scaled training techniques using model aircraft appeared to have potential in training range estimation if they could be modified to reduce the incoming-outgoing bias.

## Experiment V

The purpose of this study was to explore techniques of reduced-scale training that might provide acceptable incoming and outgoing range estimation performance under field conditions. Two training techniques were developed, designed to correct the bias obtained for inbound estimates in Experiment IV. The first technique, termed the biased training method, taught the observers a biased size-distance relationship for inbound directions and the true size-distance relationship for outbound directions. For the second, or aperture, training method, a subject was required to make his estimates while looking through his partially closed fist to reduce the complex visual environment (which it was thought might contribute to overestimations of the criterion range on the inbound portion of the flight path).

[1]For purposes of this study, the following terminology was used to describe estimation errors: If the observer who was to estimate a distance of 800 meters made this estimate when the aircraft was at 900 meters, this was defined as an error of overestimation; if the aircraft was at 700 meters, this was defined as an error of underestimation.

The subjects were trained with a 1:50-scale F-100, and tested in the Experiment III field environment. All observers received 20 trials of immediate reinforcement training with the model aircraft.

The analysis revealed a significant difference between training methods. The mean error was −14 meters for the aperture group and +127 meters for the biased group. It was found that a significant bias *did* exist between inbound and outbound range estimation performance, and that this effect was significantly reduced by training. Experiment V indicated that observers can be trained to estimate aircraft range under field conditions without using live aircraft in the training.

### Experiment VI

This study was conducted to determine the number of training trials necessary to learn to estimate a distance of 350 meters using the occlusion method (use of an occluding device as an aid in estimating) with model aircraft. At the completion of training, the subjects were tested with aircraft of different sizes to determine the extent of training transfer.

The subjects were six Army personnel and two research personnel. Training was conducted with a 1:72-scale F-4, and the occluding device was an M-14 rifle sight mounted on a BB gun. The subjects made their estimates of 350 meters by pulling the trigger of the BB gun, which stopped the moving target. If the estimate was in error, the target was moved to the correct position to provide feedback information to the trainee.

During training with the F-4, the mean error of estimation began to stabilize after 10 trials at 14% error or less. The subjects were then tested with four different aircraft: the F-4, F-104, Mig 21, and Mig 19 at scale offsets of 0, 100, 200, and 300 meters. The incoming-outgoing bias was found to be significant in the miniature situation. An increase in observer offset tended to increase range estimation accuracy except for the 300-meter offset, where judgments became overestimates. Increasing offset also tended to reduce the incoming-outgoing bias.

## Conclusions

(1) Range estimation skills were found to be improved with training. The effects of training were reductions of mean error and variability, and partial or complete elimination of constant errors of estimation.

(2) For short ranges, the finger occlusion training method yielded the best results. When longer ranges were involved and range estimation aids were not available, immediate reinforcement training appeared to be the most effective.

(3) If observers are being trained to estimate one range, a minimum of 20 training trials should be administered. A total of at least 110 trials should be given when four ranges are being trained.

(4) All studies demonstrated a consistent difference between the judgments made for incoming and outgoing directions of flight. Incoming judgments were generally large overestimations of range and outgoing judgments were relatively accurate.

(5) Another factor that tended to influence range estimation performance was aircraft elevation. This variable appeared to increase the apparent size of aircraft flying at low elevation, resulting in overestimation of the criterion range.

(6) Range estimation training methods using model aircraft appear to have a great deal of potential. At the present time, however, an adequate validation test with a carefully controlled field study has not been conducted.

# CONTENTS

# Studies on Training Ground Observers to Estimate Range to Aerial Targets

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## Chapter 1

# INTRODUCTION

### MILITARY PROBLEM

The low-altitude air assault tactics now being employed in Vietnam may require a change in the defense doctrine of the forward area gunner. Rather than a policy of concealment, one of active engagement in an air defense role may be adopted. Losses in Vietnam of both high- and low-performance aircraft indicate that the forward area soldier can function effectively in an air defense role.

The weapons that could be available in the near future for low-altitude air defense are (a) small arms organic to the infantry company, (b) the larger caliber automatic weapons, (c) the man-transportable Redeye missile system, and (d) the Chaparral air defense weapon. If the forward area gunner is to serve in this capacity, one of the prerequisites is the capability to estimate range. This capability is critical for several important reasons:

(1) Accurate range estimation will conserve ammunition by delaying fire until the aircraft is within effective range, and at the same time increase the probability of a hit by firing the maximum amount of time the aircraft is vulnerable.

(2) Since the amount of lead required to hit an aerial target is a function of distance, accurate range estimation is essential to insure the proper lead.

(3) Since almost all untrained estimates of range tend to be gross overestimates of the distance, the gunner's position would be revealed too early, which might allow the aircraft time to convert to attack.

(4) For rapid weapon systems or systems with low-capacity magazines, serious overestimation of the "open fire" range might expend the immediately available ammunition before the target is within effective range. Since some time would be required for reloading, the possibility of engagement would be lost.

### RESEARCH PROBLEM

In the event that range information or ranging aids are not available, range determination will depend on the estimates made by the forward area soldier. Man's ability to estimate range to ground targets has been widely explored (Gibson and Bergman, 1; Gibson, Bergman, and Purdy, 2; Schmidt, 3; Spencer, 4), but less is known about the ability of an observer to estimate the distance to moving aerial objects. Even less information is available concerning variables that influence range estimation accuracy and the relative effectiveness of methods of training range estimation skills.

A series of pilot studies were designed to explore the latter two areas of research. These tests were intended to provide guidelines for future research concerning range estimation training methods and variables that influence range estimation performance.

## RESEARCH METHOD

Six separate studies, which will be referred to as Experiments I through VI, were conducted. Experiments I and II were pilot studies for Work Unit SKYFIRE, Sub-Unit I. The objectives of these studies were to make an initial comparison of range estimation training methods, and to determine the effects of illumination level, aircraft elevation, and incoming-outgoing directions of flight on estimation errors.

In Experiment III, selected methods of training range estimation were more extensively examined to satisfy a consulting request from the Army. The number of distances to be estimated was increased, and the effects of incoming-outgoing directions of flight were also tested.

Experiments IV and V were pilot studies designed to compare the effectiveness of reduced-scale range estimation training with the performance level obtained from field training.

Experiment VI was one of several feasibility studies requested by the Army on a reduced-scale training program for the use of small arms in an air defense role. This study employed an occlusion method of range estimation training in the laboratory, and examined the extent to which training would generalize to different aircraft sizes.

## PERFORMANCE MEASUREMENT

### Available Measures

Several measures are available for describing the accuracy with which an individual estimates distance:

(1) Absolute error. The absolute bias or deviation of the judged distance from the true physical distance, regardless of direction of error. This measure would be of value if there were no interest in the direction of the judgmental error.

(2) Algebraic error. The bias or deviation of the judged distance from the physical distance, which takes cognizance of the direction of the error. This measure would be of interest when the direction of the error, plus or minus, has either operational or training implications, such as a desire to minimize one type of error—overestimation, for example.

(3) Percentage error. The percentage by which the absolute error or algebraic error deviates from the physical distance. It is conveniently computed by the following formula:

$$\frac{E - A}{A} \times 100 = \text{Percent Error},$$

where E is the judged distance and A is the actual distance. This measure might be used when there is little interest in analyzing judgmental errors for specific distances, and when there is interest in describing the average judgmental error over a range of physical distances.

(4) Error variability. The variability of judgmental error refers to the amount of variation or dispersion of the judgmental errors about the average error. It is a measure of judgmental precision or consistency. Several alternative statistics are available for describing error variation. The two most commonly used are probable error and standard deviation:

(a) The probable error is a statistic which describes the area of the total distribution of errors that contains 50% of the observations, if the distribution is a normal Gaussian surface. It is similar in concept to the Circle of

Equal Probability (CEP) used by artillery personnel for describing the probable distribution of rounds fired about the center of impact.

(b) The standard deviation (SD), or root mean square deviation, is the square root of the mean of the deviations about the center of impact squared. For a normally distributed set of observations, the range of +1 SD to −1 SD includes approximately 68% of the observations. The standard deviation was the measure of variation or judgmental precision used for describing the results presented in this report.

(5) Dispersion Index. The "dispersion index" (DI) may be considered as a measure of the overall accuracy of a set of measurements or judgments. In order to describe an observer's accuracy in judging a specified distance, it is necessary to state his average judgmental bias (his mean algebraic error, for example) and his judgmental consistency (the expected variation of his individual judgments about his average error or bias). The dispersion index is a statistical measure that reflects both the magnitude of the bias and the consistency (or inconsistency) of a set of observations.

The dispersion index has been defined mathematically as follows (Frederickson, Follettie, and Baldwin 5):

$$DI = \sqrt{(\text{Mean Algebraic Error})^2 + (SD)^2}$$

Statistically, it may be defined as the square root of the second moment of a distribution of observations about zero error.

Although DI information is reported in the studies described here, discussion of performance measures is limited to the two components of DI (means and standard deviations). The dispersion index may have analytical value when the primary concern is with improving overall judgmental accuracy, regardless of the source of error. In the studies described here concerning training techniques and environmental parameters, there was interest in separately assessing the effects on bias (average error) and consistency (the standard deviation).

In Experiments I and II there was only one criterion range, and the inappropriateness of using raw score estimates as a performance measure had not become apparent. When four criterion ranges were used in an analysis of variance of raw scores, the resulting distribution was skewed and variances were heterogeneous. Absolute error was excluded as a possible performance measure, since information concerning the direction of error was desirable for future research purposes.

Two other measures examined were algebraic percent error and algebraic error. The distribution of algebraic percent error scores was normal, but the measure was difficult to interpret and linearity between magnitude of error and criterion range was destroyed at short ranges. Algebraic error was the performance measure selected for all analyses because it resulted in the most normal distributions, was easily interpreted, preserved the direction of error, and provided an apparently linear relationship between magnitude of the estimation error and the criterion range.

## Overestimates Versus Underestimates

Each of these studies involved training subjects to estimate specific ranges, and feedback was given in terms of these criterion ranges. During the test trials, the range estimation task was to indicate when the aircraft reached the specified (criterion) range rather than to give an actual estimate of range at a specified time. Therefore, for any given trial, the distance estimate made was the same for all observers and equal to the criterion range. The range estimation performance measure selected for all analyses was algebraic error: Actual Aircraft Range minus Estimated Range.

The great majority of previous research studies dealing with estimation have been concerned with accuracy in estimating the distance (range) to an object (target). In such studies, errors in estimation have usually been calculated as: estimated distance to target minus actual distance to target. In the studies reported here, however, the focus has been on estimating critical or criterion distances, corresponding to the effective ranges of weapons. For these studies, errors in estimation are calculated as: actual distance to target minus criterion distance.

Errors were calculated differently in this study than in other estimation studies because interest lay in training men to engage (and cease engaging) the target when it reached certain critical distances, rather than in requesting or adjusting fire. The <u>size</u> of an error is the same when viewed as estimating a specified distance (in the present studies) or as estimating the range to a target; however, in the two views, the errors are opposite in algebraic sign. The way in which overestimation and underestimation were viewed may be described as follows:

> In <u>overestimation</u>, the observer signals that an aircraft is at a specified distance—say 800 meters—when, in fact, it is at a <u>greater</u> distance from him. That is, the observer has overestimated the amount of distance consumed by 800 meters.
>
> In <u>underestimation</u>, the observer signals that an aircraft is at the criterion distance when, in fact, it is at a <u>smaller</u> distance from him. That is, he has underestimated the amount of distance consumed by 800 meters.
>
> The algebraic value of <u>actual distance minus criterion distance</u> (i.e., Actual Aircraft Range minus Estimated Range) applies for both over- and underestimation, with the former producing positive and the latter negative values. That is, the error of an observer signaling at 900 meters instead of 800 would be recorded as an error of +100 meters, and the error of the observer signaling at 700 meters would be recorded as −100 meters.

The definitions above were selected to reflect the fundamental purposes of the training: to teach a gunner to make accurate judgments of when he should begin and cease firing his weapon. This means teaching him to make accurate judgments of a <u>specified</u> amount of space intervening between him and an object. He can then be <u>told that</u>, for example, he fired too soon, which actually means he overestimated a distance of <u>x</u> meters.

## Chapter 2

## THE EFFECTS OF DIFFERENT TRAINING METHODS ON RANGE ESTIMATION ERRORS FOR A 350-METER CRITERION RANGE

## (EXPERIMENT I)

### PROBLEM

The purpose of the first pilot study was to determine the accuracy of range estimation performance that could be expected from trained and untrained observers, and to explore various methods of training.

Horowitz and Kappauf (6) were quite successful in training distance estimation skills with an "immediate reinforcement" method of training. With this method, observers were required to make estimates of aircraft range at specified times, and after the completion of each trial they were given the aircraft's true range at the time of estimation. Previous research had also demonstrated that range estimation ability was increased by "paired associate" training, which consisted of passive observation of an aircraft flyover as slant ranges (the actual range from the observer) were announced (Applied Psychology Panel, 7; Kappauf, 8; Voss and Wickens, 9).

Using these two methods and a finger occlusion technique, attempts were made to determine whether different levels of performance would be obtained with the three different methods of training. The finger occlusion method was basically paired associate training with the observers, in addition, using an index finger as a range estimation aid.

### METHOD

Test Site. The test site for the present study was located in desert terrain north of El Paso, Texas. The terrain was essentially flat for several miles around the test area, and visibility was excellent throughout the test period.

Three parallel courses were surveyed with the midpoints at distances of approximately 90, 150, and 200 meters from Test Control. Each course was 1,000 meters long and was clearly marked with 6' x 6' numbered panels for pilot identification, as shown in Figure 1.

Instrumentation. The instrumentation consisted of a 20-channel event recorder for obtaining the observers' responses and field phone communication for test control personnel. The communication link between test control and the range assistant position 500 meters to the south provided (a) immediate range information for the instructors, and (b) the correct slant range marks on the event recorder tape.

Range information was obtained with an azimuth location device[1] calibrated to measure slant ranges of 250, 300, 350, 400, and 450 meters between the aircraft and test control. The range assistant verbally relayed the slant ranges to the instructor for the training trials.

[1]A detailed description of the azimuth location device is given in the Appendix.

Test Site, Experiment I

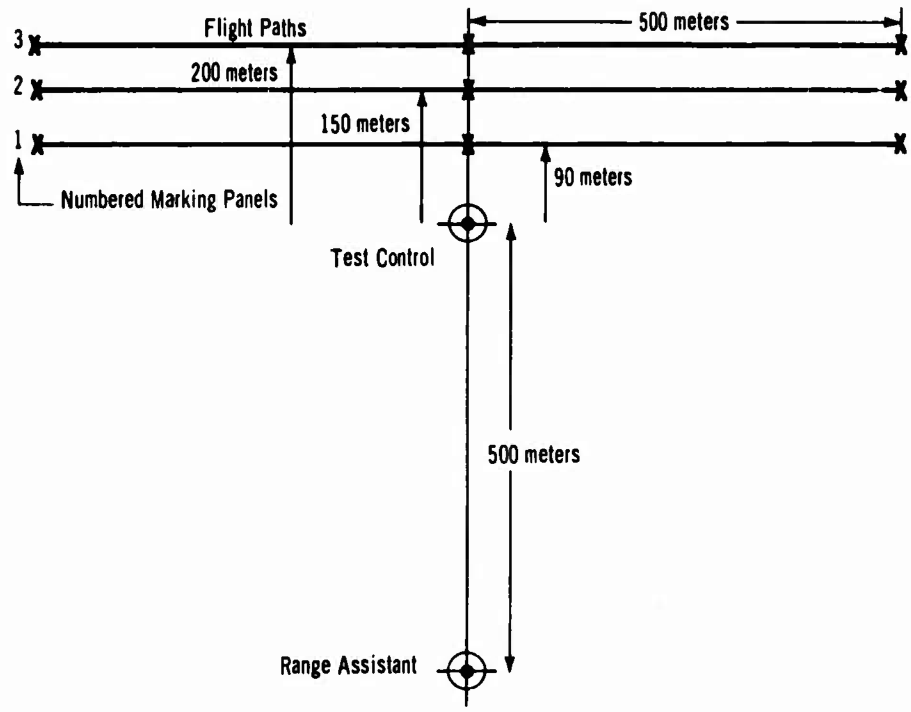


Figure 1

During the test trials, each observer was given a pushbutton that would enter his range estimation response on one event recorder channel, and the range assistant relayed the 350-meter criterion range electrically to another channel.

Aircraft. A U-6A served as the test aircraft, and the pilot was instructed to alternate the direction of each pass for a total of 48 passes. The aircraft maintained, as accurately as possible, a constant speed of 100 knots, and flew at altitudes of 175, 300, and 400 feet.

Subjects. Sixteen enlisted men served as observers for the test. All men were undergoing Advanced Individual Training and were selected by the U.S. Army Air Defense Center for the three-hour test period. The subjects were randomly assigned to one of four treatment groups for the study.

Pretest. All subjects were given an initial test of six passes to provide a performance baseline for range estimation ability. Their task was to estimate a range of 350 meters, which is the effective firing range of the M-14 rifle against aircraft. They were told to make two 350-meter estimates, one when the aircraft was incoming, and another when it was outbound.

During the test trials the subjects made their estimates by pressing a button connected to the event recorder when they thought the aircraft was 350 meters away from their position. The correct 350-meter points were recorded on the event recorder tape by electrical signals initiated by the range assistant.

Training. Starting about 10 minutes after the pretest, all trainees received 18 trials of practice in range estimation. Three aircraft flight paths were used during training. It was expected that use of different aircraft courses would prevent the trainees from using cues concerning the angular position of the aircraft from crossover and terrain cues as the basis for range estimation.

Due to the differences in training methods, it was necessary to train the subjects in two separate groups. The paired associate and finger occlusion groups were trained first, and approximately 30 minutes later the immediate reinforcement and control groups were given 18 training trials.

Paired Associate Training. For this method, the instructor announced slant ranges of 450, 400, 350, 300, and 250 meters for both incoming and outgoing directions of flight on each pass. The subjects in this group were informed that slant range to the aircraft would be announced at various points, and told to pay particular attention to apparent aircraft size at the various ranges. Their task was to watch the aircraft and try to remember its appearance at a range of 350 meters.

Finger Occlusion Training. This group was trained simultaneously with the paired associate group, and they listened to the same slant ranges being announced. Rather than studying apparent size, however, they were instructed to determine how much of the aircraft was blocked from view at 350 meters by their index finger held at arm's length. Their task was to learn to use the finger as a range estimation aid, and to try to remember how much of the aircraft was occluded by the finger at a range of 350 meters.

Immediate Reinforcement Training. The subjects in the immediate reinforcement group were informed that as the aircraft passed over they would be told to make a distance judgment at two different times during the pass of the aircraft—once incoming and once outgoing. The instructor gave a "ready" signal approximately two seconds before saying, "Estimate now!" The trainees were instructed that, as soon as they heard the word "now," they were to quickly write down their estimate of the aircraft's range at that moment. Immediately after they had recorded their answers, they were told the correct range of the aircraft at the time they made their estimate.

The ranges of 250, 300, 350, 400, and 450 meters were presented in random order for successive trials for both incoming and outgoing directions. To increase the number of presentations in the approximate range of the 350-meter criterion, they were required to make judgments of 300-, 350-, and 400-meter ranges on 24 of their 36 range estimates. The ranges of 250 and 450 meters were presented six times each, while the other three ranges were given eight times each.

Control Group. The subjects in the control group were told to continue estimating the incoming and outgoing 350-meter ranges just as they did during the pretest. They were placed approximately 20 feet behind the immediate reinforcement group to prevent them from hearing the correct ranges being announced after each pass.

Posttest. The posttest consisted of six aircraft passes, and was conducted in exactly the same manner as the pretest.

## RESULTS

The performance measure used for analysis of the data collected in this study was algebraic error of estimation. The data were analyzed nonparametrically because distributions were positively skewed.

There was a statistically significant difference[1] between pretest and posttest range estimation performance ($p < .01$). The overall mean errors for the pretest and posttest were +229 meters and +53 meters, respectively.

The difference between incoming and outgoing directions of flight was also found to be statistically significant[2] for both the pretest ($p < .01$) and posttest

[1]Wilcoxon matched-pairs signed-ranks test (Siegel, 10) ($N = 16$, $T = 0$).
[2]Wilcoxon test ($N = 16$, $T = 0$; $N = 16$, $T = 23$).

(p < .02). The overall mean error for the incoming direction was +272 meters and the outgoing mean error was +10 meters.

Analyses were m. 'e to determine whether the various offsets of the aircraft's course affected range estimation performance, but no significant differences were obtained.[1] Nor were significant differences found in average range estimation accuracy among the four groups for either the pretest or posttest conditions.[2]

Range estimation performance for each group is presented in Figures 2 and 3 in terms of mean error and standard deviation as a function of testing conditions. The mean errors for each group as a function of testing conditions and direction of flight are presented in Figures 4 and 5. The mean errors and standard deviations for all groups and experimental conditions are presented in Table 1.

**Range Estimation Error as a Function of Groups and Testing Conditions, Experiment I**

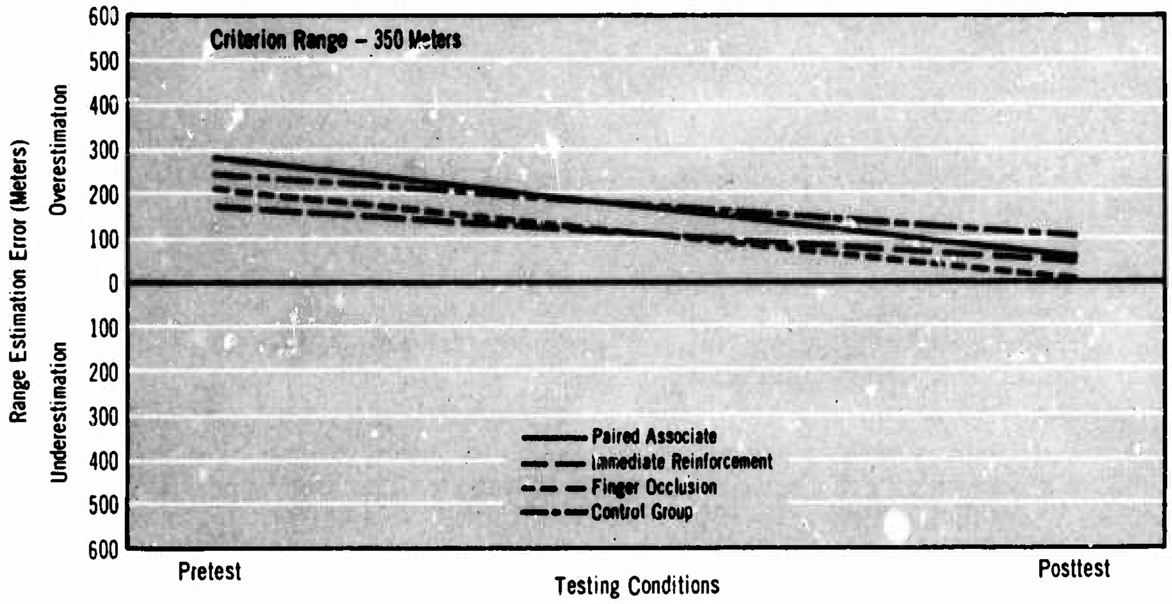


Figure 2

**Standard Deviation as a Function of Groups and Testing Conditions, Experiment I**

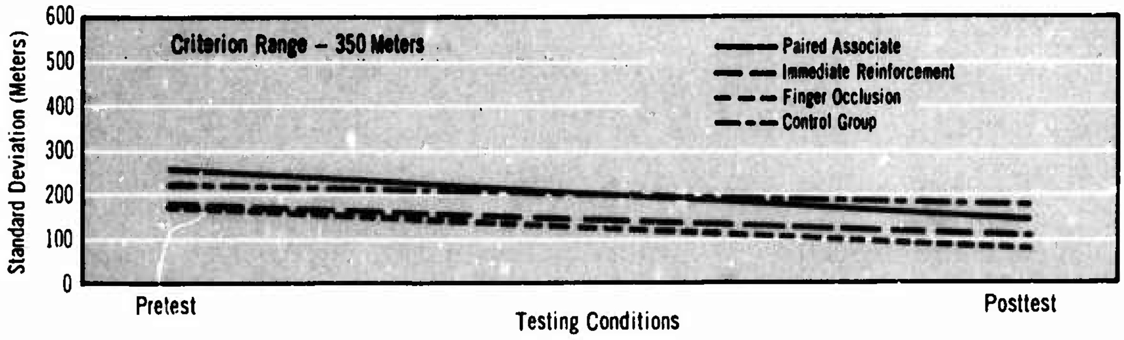


Figure 3

[1]Friedman two-way analysis of variance (10).
[2]Kruskal-Wallis one-way analysis of variance (10).

Pretest Range Estimation Error as a Function of Groups and Direction of Flight, Experiment I

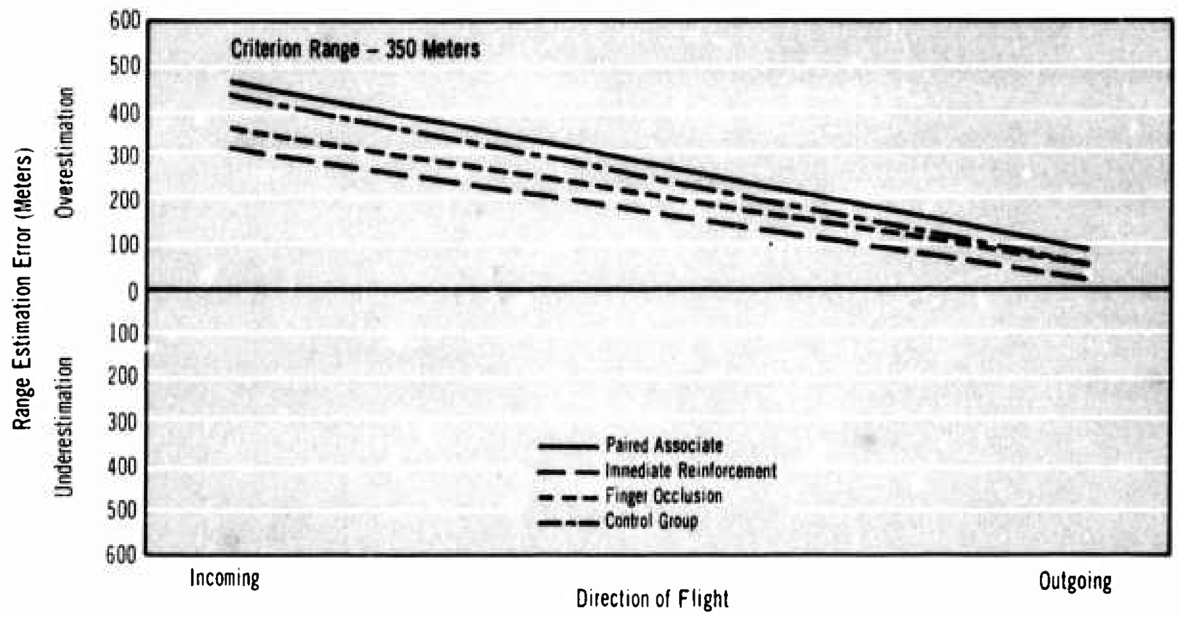


Figure 4

Posttest Range Estimation Error as a Function of Groups and Direction of Flight, Experiment I

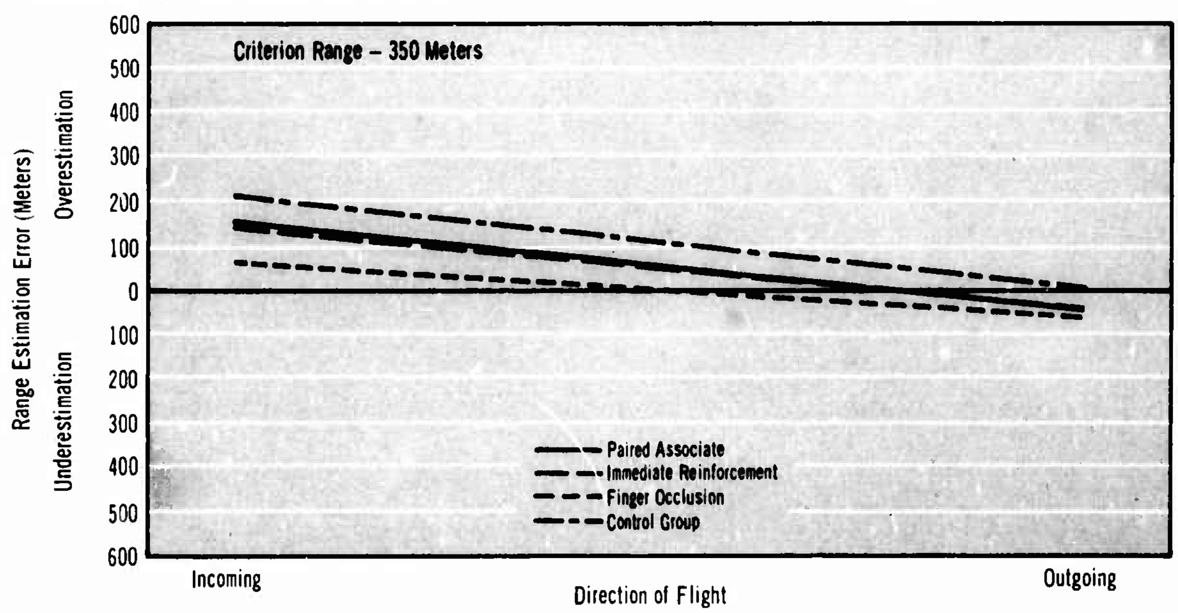


Figure 5

Table 1

**Mean Errors and Standard Deviations for All Treatment Conditions, Experiment I**

*(Meters)*

| Training Group | N | Pretest Incoming | Pretest Outgoing | Posttest Incoming | Posttest Outgoing |
|---|---|---|---|---|---|
| Immediate Reinforcement | 4 | | | | |
| Mean Error | | +320 | +25 | +145 | −48 |
| Standard Deviation (SD) | | 130 | 63 | 61 | 27 |
| Dispersion Index (DI)[a] | | 345 | 68 | 157 | 55 |
| Paired Associate | 4 | | | | |
| Mean Error | | +472 | +94 | +155 | −49 |
| SD | | 240 | 65 | 141 | 11 |
| DI | | 530 | 114 | 210 | 50 |
| Finger Occlusion | 4 | | | | |
| Mean Error | | +365 | +58 | +68 | −60 |
| SD | | 82 | 87 | 37 | 6 |
| DI | | 374 | 105 | 77 | 60 |
| Control Group | 4 | | | | |
| Mean Error | | +438 | +58 | +214 | +2 |
| SD | | 121 | 160 | 182 | 89 |
| DI | | 454 | 170 | 281 | 89 |
| Total | 16 | | | | |
| Mean Error | | +399 | +59 | +145 | −39 |
| SD | | 165 | 85 | 132 | 52 |
| DI | | 432 | 103 | 196 | 65 |

[a]Dispersion Index $= \sqrt{(\text{Mean Algebraic Error})^2 + (\text{SD})^2}$, as defined on page 5.

DISCUSSION

The available literature on range estimation performance had indicated that range estimates would be characterized by large average errors and high variability, and that these errors could be reduced with various types of training (7, 6, 8, 9). The findings of the present study are certainly consistent with past research.

Learning of range estimation skills was demonstrated by the significant difference between pretest and posttest performance, with the overall error being reduced from +229 meters to +53 meters after training. Additional effects of training were substantial reductions of variability, with the standard deviations for the training methods being reduced approximately 100 meters between testing conditions. At least for the short time periods involved, range estimation skills are subject to training which serves to increase accuracy and reduce variability, thus reducing the average discrepancy of the estimates from the true range that is reflected in the dispersion index discussed earlier.

No significant differences were found between the four experimental groups, partly because the control group inadvertently received knowledge of aircraft range. Since it was not feasible to train each group separately, the control group received their practice at the same time that the immediate reinforcement group was being trained nearby, and it was not realized that the control subjects overheard the range information until half of the training trials had been completed. As a result, the posttest scores of the control group reflect both effects of practice and knowledge of range. With reference to Figure 2, the reduction of mean error between testing conditions was approximately equivalent for the control group and the immediate reinforcement training. The variability of estimation, however, was reduced considerably more for the training groups than it was for the control group.

The direction of aircraft flight at the time a judgment was required had a significant effect on range estimation performance. As shown in Figures 4 and 5, the pretest performance of all groups was an overestimation of the 350-meter range for both directions, but after training the incoming judgments were overestimations and outgoing judgments were underestimations. These differences between testing conditions indicated that the training partially reduced the incoming-outgoing bias. Since only 18 training trials were given and the bias was reduced, it seems that with additional training trials the bias could be further reduced.

For the finger occlusion group using an aid for judging aircraft range, no difference in performance would have been expected as a function of direction of flight. Since the bias was also observed for this group, there may have been a measurable difference in the aircraft's subtended visual angle between incoming and outgoing aircraft aspects.

Aircraft speed may have been another influential factor in the incoming-outgoing bias. Almost all incoming judgments of the 350-meter range were large overestimations while outgoing judgments tended to be underestimations. In general, the observers were making their estimates of range too soon, which may reflect the effects of target motion. They may have attempted to anticipate the criterion range to counteract the influence of aircraft speed.

Another explanation might be that as the aircraft passed the test site, an anchor for distance estimation was established at the crossover point. All groups were more accurate in estimating the outgoing direction for both testing conditions.

First vs. second judgment may have been another contributor to the bias. The two responses may not have been independent and the incoming judgment may have served as practice for the outgoing judgment. That is, the observers may have corrected their outgoing judgments on the basis of their conception of errors made on the incoming estimates. If practice effects were transferred to the outgoing judgment, incoming judgments would be expected to be less accurate and more variable. The data also supported this hypothesis.

The results of this pilot study indicated a need for additional comparisons of training methods. It was shown that significant improvements in range estimation performance resulted from training. However, there was no reliable variation in performance associated with different training methods, perhaps due to the small number of observers serving in each group.

One variable that was demonstrated to have a significant effect on range estimation performance was direction of aircraft flight. An effective range estimation training method must either eliminate the bias with training or employ correction factors for it. If the bias cannot be sufficiently reduced with training, estimates of the magnitude of the incoming-outgoing errors and further understanding of the operation of the bias could probably be obtained by studying the variables of aircraft aspect, aircraft speed, anchors for distance estimation, and first vs. second responses.

## Chapter 3

## THE EFFECTS OF AIRCRAFT ELEVATION AND AMOUNT OF ILLUMINATION AT THE EYE ON RANGE ESTIMATION ERRORS FOR A 350-METER CRITERION RANGE

## (EXPERIMENT II)

### PROBLEM

The objectives of this experiment were to explore two variables hypothesized to affect range estimation performance—aircraft elevation and amount of illumination at the eye. Both hypotheses were based on the assumption that apparent size is the primary cue for distance estimation, and that apparent size and apparent distance are inversely related.

Several investigators have indicated that an object at low elevation may tend to have larger apparent size than an object at high elevation (Kaufman and Rock, **11**; Rock and Kaufman, **12**). If this elevation effect is operative with aircraft, apparent aircraft size would decrease as aircraft elevation increases. Therefore, judgments of the criterion range to an aircraft at low elevation could be expected to be overestimated relative to an aircraft at high elevation.

Under conditions of low illumination the contour of the aircraft presumably would be ill-defined, tending to produce smaller apparent aircraft size. With smaller apparent size, range estimates made under low illumination should tend to be underestimated relative to judgments made with high illumination (Coules, **13**; Gibson and Bergman, **1**).

### METHOD

Experimental Situation. Since high variability and large errors are generally associated with untrained range estimation performance, trained observers were used in this study to prevent this source of error from obscuring the experimental variables. To satisfy this requirement, the subjects used in Experiment I participated in this research, with approximately 20 minutes separating the two studies. The conditions that remained the same between studies were methods of obtaining range information, the aircraft, aircraft speed, test site, instrumentation, and the subjects.

Altitude. The aircraft courses remained the same but, to permit testing of the elevation hypothesis, the aircraft was required to fly at two widely separated altitudes. The low altitude of 75 feet produced a target 9° above the horizon at crossover, and the high altitude of 400 feet resulted in a target 55° above the horizon. For courses 1B and 2A, slant crossing range was held constant at 150 meters.

As a result, when the aircraft reached the criterion range of 350 meters on either course, the aircraft's lateral aspect angle and its angular position from the observers along the flight line were identical. Attempts were made to control ventral aircraft aspect since the views obtained for each course were considerably different. The pilot was instructed to tilt the wing toward test control down when flying course 1B, and to tilt it up when on course 2A.

In terms of aircraft aspect, the amount of ventral surface visible was reduced on course 1B and increased on course 2A.

To avoid the contamination of either high or low elevation flights with other aircraft elevations, the training received in Experiment I was conducted at a midpoint elevation of 32° using courses 1A, 2B, and 3. The courses and altitudes utilized in both experiments are diagrammatically represented in Figure 6.

Illumination. Two levels of illumination were achieved through the use of variable density goggles. Performance under normal daylight illumination was compared with a condition of reduced illumination that was approximately equivalent to an overcast day. The goggles were adjusted to near maximum polarization, and the percentage of light transmitted was reduced to approximately 5% of the ambient illumination.

Testing Situation. The task for this experiment was to estimate a range of 350 meters for both incoming and outgoing directions. The subjects made their estimates by pressing a button when they thought the aircraft was at a range of 350 meters.

The experiment consisted of a total of 20 aircraft passes—10 passes at high altitude followed by 10 passes at low altitude. Time did not permit counterbalancing of the elevation variable, but during all 20 passes the order in which subjects wore goggles was counterbalanced across experimental conditions. The type of training received by the subjects in each goggle and non-goggle group was also balanced across the four training groups.

## RESULTS

The algebraic errors of estimation for this study were analyzed non-parametrically because of positively skewed distributions.

**Cross Section of the Flight Paths for Experiments I and II**

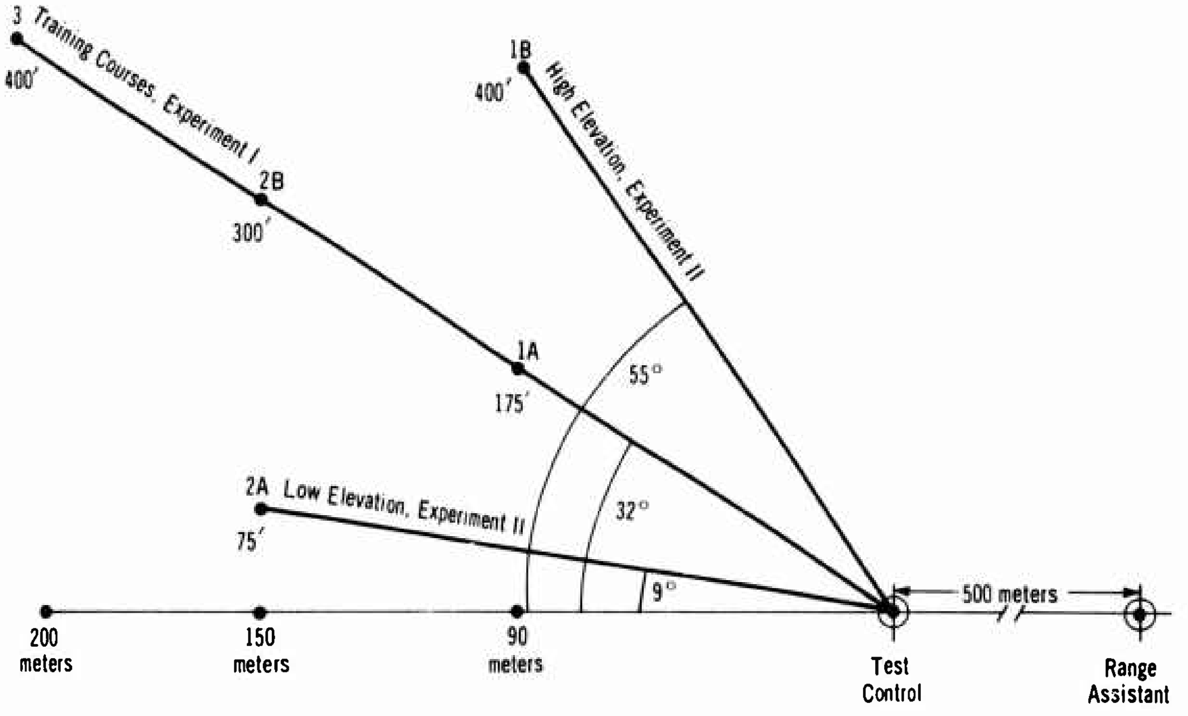


**Figure 6**

A statistically significant difference[1] was found between estimates made for incoming and outgoing directions of flight ($\underline{p} < .01$). The overall mean errors for incoming and outgoing directions of flight were +140 meters and −21 meters respectively. A significant difference[2] also was found between the average estimates made for the two elevation angles ($\underline{p} < .01$). The mean range estimation error was +88 meters at low elevation and +32 meters for high elevation.

The effects of the illumination variable were also tested, but a significant difference between conditions was not obtained. Nor were significant differences found between the four groups.[3]

The mean errors and standard deviations for high and low elevation conditions are shown in Figures 7 and 8. The mean errors and standard deviations for all groups and experimental conditions are listed in Table 2.

**Range Estimation Error for Levels of Aircraft Elevation, Experiment II**

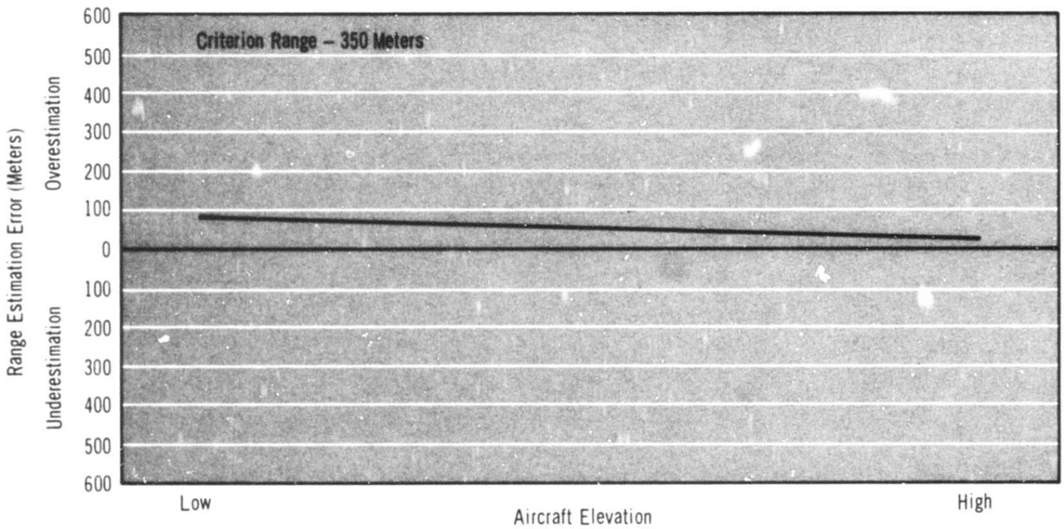


Figure 7

**Standard Deviation for Levels of Aircraft Elevation, Experiment II**

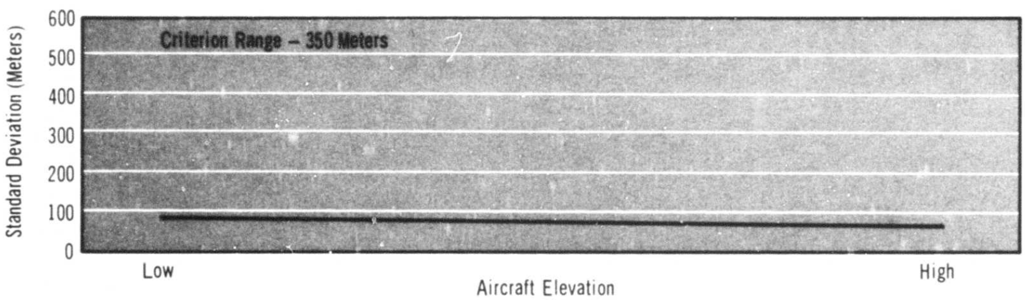


Figure 8

[1]Wilcoxon matched-pairs signed-ranks test ($N = 16$, $T = 0$).
[2]Wilcoxon test ($N = 16$, $T = 15.5$).
[3]Kruskal-Wallis one-way analysis of variance.

Table 2

**Mean Errors and Standard Deviations for All Treatment Conditions, Experiment II**
*(Meters)*

| Training Group | N | Low Illumination | | | | High Illumination | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | High Elevation | | Low Elevation | | High Elevation | | Low Elevation | | |
| | | In | Out | In | Out | In | Out | In | Out | |
| Immediate Reinforcement | 4 | | | | | | | | | |
| Mean Error | | +142 | -43 | +172 | -4 | +106 | -37 | +217 | +9 | +70 |
| SD | | 77 | 17 | 161 | 103 | 39 | 11 | 128 | 52 | 130 |
| DI | | 162 | 46 | 236 | 103 | 113 | 39 | 252 | 53 | 148 |
| Paired Associate | 4 | | | | | | | | | |
| Mean Error | | +125 | -71 | +220 | +52 | +67 | -53 | +137 | +8 | +61 |
| SD | | 113 | 49 | 96 | 38 | 117 | 32 | 54 | 33 | 119 |
| DI | | 169 | 86 | 240 | 64 | 135 | 62 | 147 | 34 | 134 |
| Finger Occlusion | 4 | | | | | | | | | |
| Mean Error | | +16 | -65 | +73 | -27 | +27 | -64 | +109 | 29 | +5 |
| SD | | 37 | 17 | 51 | 26 | 39 | 14 | 58 | 21 | 69 |
| DI | | 40 | 67 | 89 | 37 | 47 | 66 | 123 | 36 | 69 |
| Control Group | 4 | | | | | | | | | |
| Mean Error | | +204 | -16 | +229 | -21 | +157 | +10 | +240 | +19 | +103 |
| SD | | 157 | 73 | 151 | 87 | 114 | 43 | 142 | 45 | 161 |
| DI | | 257 | 75 | 274 | 90 | 194 | 44 | 279 | 49 | 191 |
| Total | 16 | | | | | | | | | |
| Mean Error | | +123 | -49 | +173 | 0 | +89 | -36 | +176 | +2 | +60 |
| SD | | 124 | 50 | 138 | 78 | 99 | 40 | 116 | 80 | 129 |
| DI | | 175 | 70 | 221 | 78 | 133 | 54 | 211 | 80 | 142 |

## DISCUSSION

This study appears to offer a good demonstration of the effect of aircraft elevation on estimation errors. The errors of overestimation were greater for the low-elevation aircraft, possibly indicating larger apparent size. Additional indication that the elevation variable influenced performance came from the observation that ventral aircraft aspect tended to operate in the opposite direction. Attempts were made to control ventral aircraft aspect, but only partial control was achieved. Although no measurements were made, the aircraft at high elevation almost certainly presented a larger solid angle than the one at low elevation.

Another possible source of error in the elevation variable was the confounding of the aircraft's offset (the distance to the ground projection of the flight path) and its altitude. However, it seemed that the advantages obtained would outweigh the potential detrimental effects of confounding. The decision to hold slant-crossing range constant automatically confounded aircraft altitude and offset. By holding aircraft slant-crossing range constant, many of the variables related to different courses were also held constant: (1) For any given range, the aircraft's lateral aspect angle and its angular position from the observers along the flight line were identical for the two courses. (2) An important dynamic factor thus held constant was aircraft angular velocity which, based on results from Experiment I, appeared to be directly related to the variability of range estimation errors among observers; that is, the greater the angular velocity, the less consistency there was among the observers' judgments of the criterion range.

Thus the attributes of the stimulus situation that were controlled by holding slant crossing range constant were more relevant to the task than the confounding of the aircraft's offset distance and its altitude.

Although no significant difference was obtained between the illumination conditions in this study, it seems that a larger difference would be more likely to occur with the use of longer criterion ranges. With a criterion range of 350 meters, the aircraft was so prominent in the visual field that any reduction of contour definition could only make a relatively slight contribution to range estimation error.

It was of interest to note that the magnitude of the incoming-outgoing difference was less when the target was at high elevation, suggesting that aircraft elevation may have been partly responsible for the bias. The difference between incoming and outgoing errors was smaller at high elevation than it was at low elevation, and the variability of estimation was also reduced on high elevation passes.

The most important finding of this pilot study was that aircraft elevation had a significant effect on range estimation performance. A differential reduction of the incoming-outgoing bias was also observed as a function of aircraft elevation. Further studies of incoming-outgoing directions of flight with various levels of target elevation may assist in relating the effects of the bias to either elevation effects or the influence of terrain factors. The variable of illumination should not be regarded as unimportant without more research involving longer criterion ranges and further reductions of illumination at the eye.

Chapter 4

## THE EFFECTS OF DIFFERENT TRAINING METHODS ON RANGE ESTIMATION ERRORS FOR CRITERION RANGES OF 400, 800, 1,500, AND 2,500 METERS

### (EXPERIMENT III)

### PROBLEM

Experiment I indicated that for unaided range estimation, the immediate reinforcement and paired associate methods were both effective for training for a range of 350 meters, but no statistical decision could be made concerning the selection of the best method. The purpose of the present study was to determine an acceptable unaided method—that is, no job aid—of training range estimation for the ranges of 400, 800, 1,500, and 2,500 meters. Several different methods of describing range estimation performance were also examined.

The four training methods used in the experiment were immediate reinforcement, immediate reinforcement with supplementary helicopter training, paired associate training, and paired associate training with supplementary helicopter training. It was hypothesized that supplementary helicopter training would improve the observer's ability to estimate range by providing a stationary target for learning distances and also smaller intervals between ranges than could be obtained with the jet aircraft.

General Test Area, Experiment III

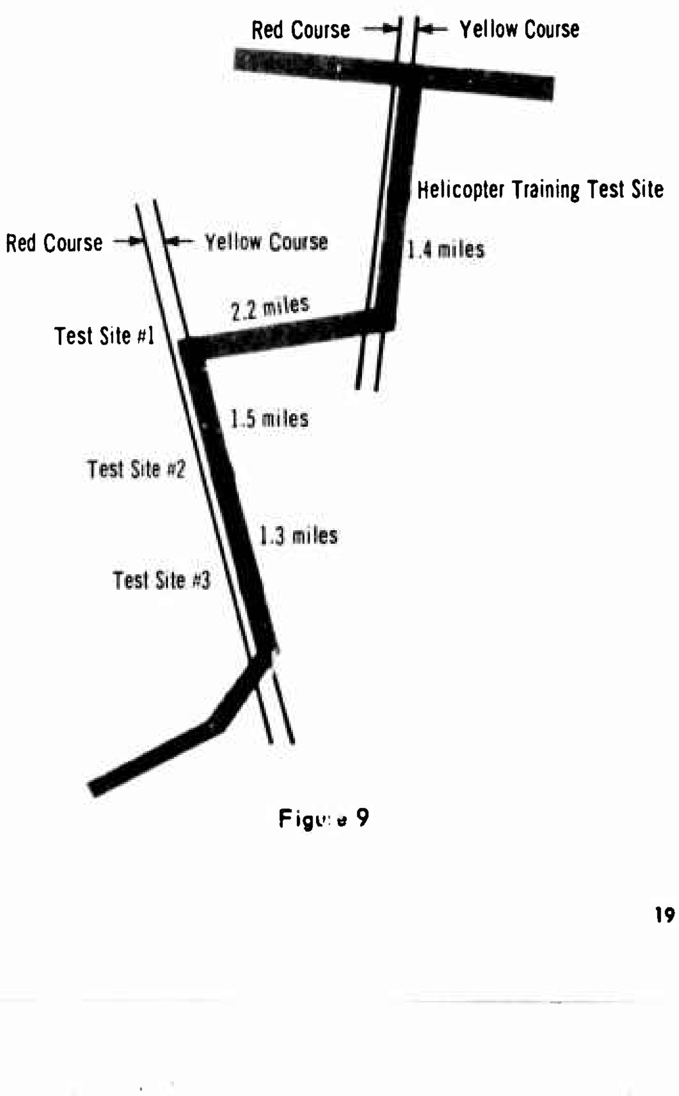


Figure 9

### METHOD

Test Site. The general test area consisted of slightly rolling terrain and the test sites were located on four ridgelines. Two separate test areas were occupied, one for jet aircraft and one for helicopter, to permit simultaneous training of two groups using two types of aircraft. The specific layout of the training area is shown in Figures 9 and 10.

The jet course consisted of two parallel flight lines, each 5.5 miles long.

Jet and Helicopter Test Sites, Experiment III

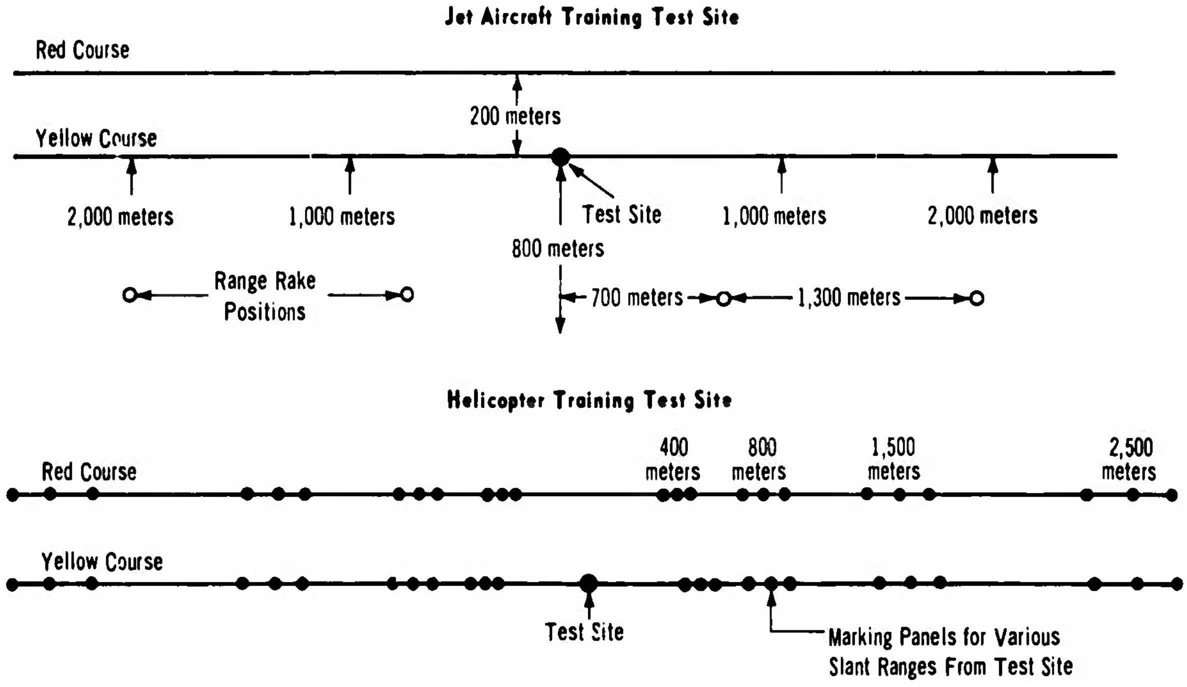


Figure 10

The first was marked primarily by a road with three additional fluorescent yellow 6' x 6' panels. The second flight line, 200 meters to the west, was marked with 11 fluorescent red 6' x 6' panels. The three test sites on the yellow flight line were provided so that the training and testing for any one day could be conducted at different sites, and to allow each day's training to be given a different position. For the jet course, the colored panels served only to mark the flight line, and range information was obtained with azimuth location devices similar to those used previously.

On the helicopter course, however, 48 horizontal ground panels were required for the various slant ranges. The helicopter could be located at any of the programed slant ranges by maintaining position over the appropriate panel. The panels were 6' x 6' sections of target cloth painted fluorescent red and yellow, and each color series was numbered 1-24.

Instrumentation. A communication link between test control and the four range assistant positions was created by using a five-watt citizens' band base station and four one-watt transceivers. During the test trials, the correct slant ranges were entered on each of two event recorders by modifying the citizens' band equipment to transmit a pulsed signal. The observers' responses were entered on the event recorders by means of individual pushbuttons.

Range information was obtained with an azimuth location device similar to that used in Experiment I. This study, however, required the use of four devices, each with the capability of measuring additional ranges. During the training trials, correct slant ranges were transmitted by voice from the range assistants to the instructors. The requirement for range information pertained only to the jet course, since knowledge of slant range on the helicopter course depended only on the pilot correctly following the flight schedule. The Appendix contains more specific descriptions of the instrumentation.

Aircraft. Two types of aircraft were scheduled for the study—the F-100 aircraft and the H-23 helicopter. The pilot of the jet aircraft was instructed to alternate the direction of each pass and maintain a constant speed of 400 knots while over the flight line. The helicopter pilot was also instructed to alternate the direction of each pass, but to fly at whatever speed enabled him to visually sight the marking panels. After the pilot had acquired the three panels for any given trial and direction, he was instructed to maintain position over each panel for approximately 10 seconds.

Subjects. Twenty-eight enlisted men served as observers for the test. All men were trained M-42 gunners provided by the U.S. Army Air Defense Center for the three-day test period. The subjects were randomly assigned to one of four range estimation training methods.

Testing Period and Procedure. On the first 12 trials of the first day, all subjects were given a pretraining test (pretest) to provide a performance baseline that would have been used to evaluate the effectiveness of the training methods. Unfortunately, instrumentation failure prevented the collection of any data on the first day. After the pretest the subjects were divided into four groups and received 36 training trials each day for three days. Following the training trials, the last 12 trials of each day were devoted to posttesting at a different site. The pretest, however, was given only on the first day. The training and testing sequence was as follows:

| Test Day | Activity | Location |
|---|---|---|
| First Day | Pretest | Site 1 |
| | Training | Site 1 |
| | Posttest | Site 2 |
| Second Day | Training | Site 2 |
| | Posttest | Site 3 |
| Third Day | Training | Site 3 |
| | Posttest | Site 1 |

The use of different sites for training and testing was incorporated because recent HumRRO studies have suggested that certain terrain features may be used as cues by the subjects to indicate specific ranges (5). Since the subjects had ample time during the 36 training trials to acquire terrain cues, they were moved to a new and unfamiliar site for testing.

Pretest. Prior to the pretest, all subjects were given a numbered card which designated their event recorder channel number. The card also had listed the ranges which they were required to learn—400, 800, 1,500, and 2,500 meters. These ranges represent the approximate open firing ranges for various forward area gun systems.

Before testing began, the subjects were informed of the general purpose of the study, and the specific ranges that they would be trained to estimate were stressed. They were instructed to make two estimates of range each time the aircraft passed over—one for the incoming direction and the other for the outgoing direction. Just before the aircraft entered the course for each pass, they were verbally given the two ranges that they were required to estimate. This procedure was followed for all pretest and posttest trials.

Training. The basic training for all groups consisted of immediate reinforcement or paired associate training with jet aircraft. The helicopter groups, however, received one-third of their training trials with a helicopter and the remainder with jet aircraft.

The ranges used during training for each type of aircraft and each criterion range were as follows:

| Criterion Range | Training Ranges |
|---|---|
| Jet Aircraft | |
| 400 meters | 300, 400, 600, and 800 meters |
| 800 meters | 400, 600, 800, 1,000, and 1,200 meters |
| 1,500 meters | 1,100, 1,300, 1,500, 1,700, and 1,900 meters |
| 2,500 meters | 2,100, 2,300, 2,500, 2,700, and 2,900 meters |
| Helicopter | |
| 400 meters | 350, 400, and 450 meters |
| 800 meters | 700, 800, and 900 meters |
| 1,500 meters | 1,300, 1,500, and 1,700 meters |
| 2,500 meters | 2,100, 2,500, and 2,900 meters |

For helicopter training, the panels at the 400-meter criterion range were separated by 50 meters; the 800-meter panels by 100 meters; the 1,500-meter panels by 200 meters; and the 2,500-meter panels by 400 meters. The distances between panels for each of the criterion ranges were selected to approximate the minimum change in ground distance that can be discriminated at each range (Katchmar, Jelinck, and Hodge, 14; Teichner, Kobrick, and Wehrkamp, 15).

During the training trials, the immediate reinforcement groups and the paired associate groups were located approximately 75 feet apart and on opposite sides of the road defining the flight path. The separation was necessary because the groups were given different instructions, and it was critical for the feedback to be inaudible between the groups.

Immediate Reinforcement Training. The immediate reinforcement groups were told to make an estimation on command at two different points along the flight line—once incoming and once outgoing. The instructor gave a "ready" signal approximately two seconds before saying "estimate now." As soon as the observers heard the word "now," they quickly recorded their estimate of the aircraft's range at that moment. Immediately after the trial had been completed, they were told the correct ranges for that pass.

On one-third of their training trials, the immediate reinforcement groups were told to make an estimate on command when the aircraft was at one of the criterion ranges, and the bracketing ranges were randomly assigned for the remaining trials.

Paired Associate Training. For the paired associate groups, a series of five consecutive ranges were announced for both incoming and outgoing directions. Each series consisted of one of the criterion ranges accompanied by the bracketing ranges. The subjects were told to pay particular attention to the apparent size and distance of the aircraft as the ranges were announced, and to keep in mind the ranges they were being trained to estimate.

Immediate Reinforcement - Helicopter and Paired Associate - Helicopter Training. The helicopter groups received one-third of all their training trials on the helicopter course. On any one day, there were 36 training trials, with helicopter training conducted on trials 13-24. These were the only trials during which the helicopter groups were not on the jet course; the other two groups were on the jet course at all times.

The training procedures for the helicopter were the same as for the jet aircraft except that the helicopter groups observed a stationary aerial target. The instructors announced ranges and called "estimate now" only after the helicopter was holding position over one of the panels. The subjects in the helicopter groups were told that the jet aircraft was approximately three times as large as the helicopter; otherwise, the instructions for both immediate reinforcement and paired associate groups were the same as those for the jet course.

Posttest. The posttest was conducted in the same manner as the pretest, and was administered on the last 12 trials for each of the three days.

RESULTS

Training Methods. The algebraic errors of estimation for Posttest 3 were analyzed in a Lindquist Type VI design (12). The between-subject effects were the various training methods employed, and the within-subject factors were range to be estimated and direction of flight. The analysis of variance summary is presented in Table 3. The mean errors and standard deviations for all groups and experimental conditions are listed in Table 4.

Table 3

**Analysis of Variance of Posttest 3 for All Training Methods, Experiment III**

*(Mean Error in Meters)*

| Source of Variation | $df$ | MS | $F$ | $p$ |
|---|---|---|---|---|
| Between Ss | 23 | 199.129 | 1.42 | |
| A (Training Methods) | 3 | 592.934 | 4.23 | .05 |
| Error A | 20 | 140.049 | | |
| Within Ss | 168 | 76.393 | | |
| B (Criterion Range) | 3 | 222.576 | 2.55 | |
| AB | 9 | 227.944 | 2.61 | .05 |
| Error B | 60 | 87.243 | | |
| C (Direction of Flight) | 1 | 196.544 | 2.22 | |
| AC | 3 | 64.225 | < 1 | |
| Error C | 20 | 88.563 | | |
| BC | 3 | 98.200 | 2.76 | .05 |
| ABC | 9 | 32.680 | < 1 | |
| Error BC | 60 | 35.517 | | |

Training method was the only statistically significant main effect obtained. The differences between group means were tested with Tukey's multiple comparison test (Federer, 16), and a significant difference found was between the immediate reinforcement - helicopter group and the paired associate - helicopter group ($p < .05$).

The significant interactions were between training methods and criterion range and between criterion range and direction of flight. These interactions are graphically represented in Figures 11 and 12. When Tukey's test was applied to the training-methods by criterion-range interaction, it was found that all significant differences occurred at the 2,500-meter range. The mean error for the paired associate - helicopter group was significantly larger than six other means. For the criterion-range by direction-of-flight interaction, incoming mean errors for the ranges of 800 meters and 1,500 meters were significantly different from the three largest negative errors.

Immediate Reinforcement Training. An additional analysis was performed on the algebraic errors of estimation for the immediate reinforcement training

Table 4

**Mean Errors and Standard Deviations for All Training Methods (Posttest 3), Experiment III**

*(Meters)*

| Training Group | N | 400 Meters | | 800 Meters | | 1,500 Meters | | 2,500 Meters | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | In | Out | In | Out | In | Out | In | Out | |
| Immediate Reinforcement | 6 | | | | | | | | | |
| Mean Error | | -70 | -50 | -14 | -39 | -100 | -37 | -150 | -52 | -64 |
| SD | | 124 | 126 | 187 | 175 | 267 | 194 | 438 | 374 | 262 |
| DI | | 142 | 136 | 188 | 179 | 285 | 198 | 463 | 378 | 270 |
| Immediate Reinforcement – Helicopter | 6 | | | | | | | | | |
| Mean Error | | -61 | -68 | +143 | -29 | +389 | +67 | +111 | +177 | +91 |
| SD | | 67 | 37 | 210 | 89 | 215 | 237 | 543 | 228 | 289 |
| DI | | 91 | 77 | 254 | 94 | 444 | 246 | 554 | 289 | 303 |
| Paired Associate | 6 | | | | | | | | | |
| Mean Error | | -129 | -60 | -70 | -142 | +49 | -197 | -208 | -214 | -121 |
| SD | | 106 | 76 | 159 | 116 | 346 | 142 | 348 | 524 | 285 |
| DI | | 167 | 97 | 174 | 183 | 349 | 243 | 405 | 566 | 310 |
| Paired Associate – Helicopter | 6 | | | | | | | | | |
| Mean Error | | -4 | +31 | +54 | -42 | -81 | -286 | -375 | -600 | -163 |
| SD | | 145 | 118 | 171 | 129 | 152 | 127 | 450 | 175 | 303 |
| DI | | 145 | 122 | 179 | 136 | 172 | 313 | 586 | 625 | 344 |
| Total | 24 | | | | | | | | | |
| Mean Error | | -66 | -37 | +28 | -63 | +64 | -113 | -156 | -172 | -64 |
| SD | | 122 | 104 | 199 | 139 | 322 | 227 | 482 | 452 | 301 |
| DI | | 139 | 110 | 201 | 153 | 328 | 254 | 507 | 484 | 308 |

**Range Estimation Error as a Function of Training Method and Criterion Range, Experiment III**

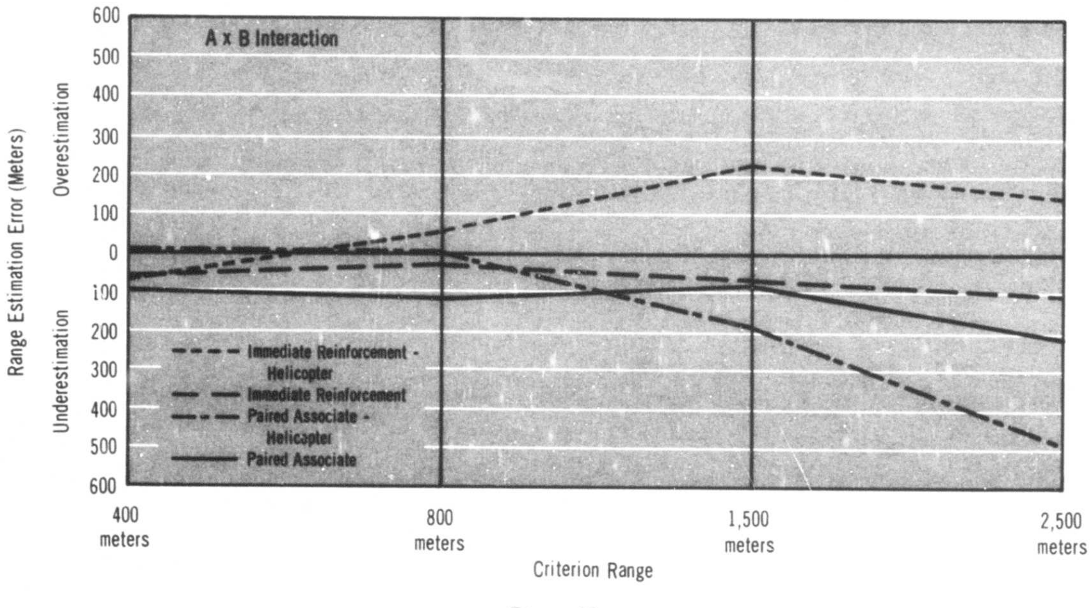


Figure 11

Range Estimation Error as a Function of Criterion Range and Direction of Flight, Experiment III

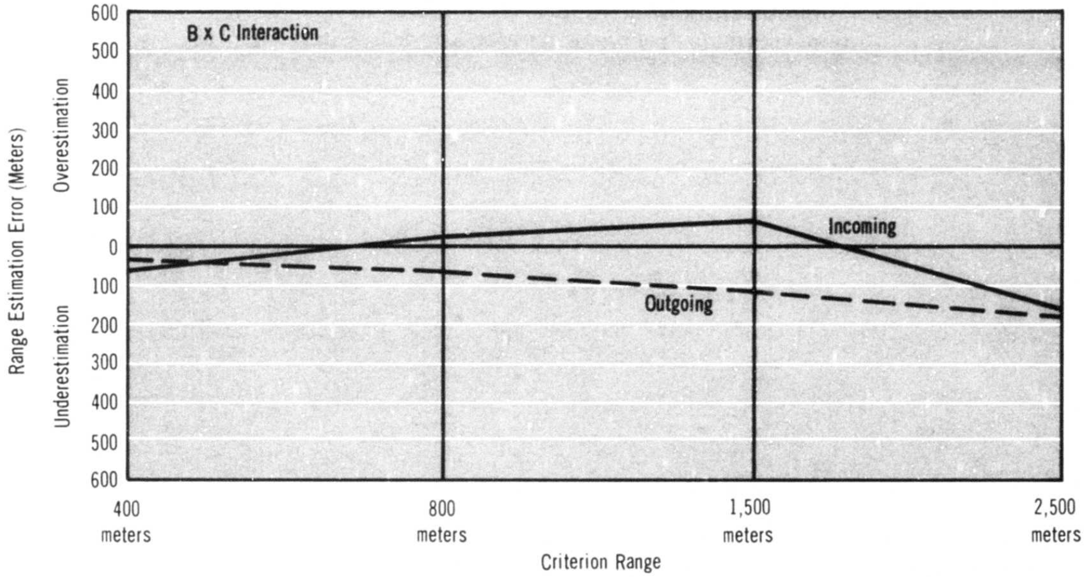


Figure 12

group obtained during Posttests 2 and 3. The variables tested were amount of training, range to be estimated, and direction of flight. The analysis of variance summary is presented in Table 5, and the mean errors and standard deviations for all experimental conditions are listed in Table 6.

Amount of training was the only statistically significant main effect obtained with the analysis. The errors of estimation for Posttest 2 were significantly larger than the errors for Posttest 3 (+67 meters and –10 meters).

The significant interactions were (a) amount-of-training by direction-of-flight, and (b) amount-of-training by criterion-range by direction-of-flight. The significance of the amount-of-training by direction-of-flight interaction (Figure 13) was due to significant differences between the mean error for the incoming direction during Posttest 2 and all other conditions, as determined by Tukey's test.

Several significant differences between pairs of

Table 5

**Analysis of Variance of Posttests 2 and 3 for Immediate Reinforcement Training, Experiment III:**
**Amount of Training, Criterion Range, Direction of Flight**
*(Mean Error in Meters)*

| Source of Variation | *df* | MS | *F* | *p* |
|---|---|---|---|---|
| S (Subjects) | 6 | 355,357 | | |
| A (Amount of Training) | 1 | 320,572 | 13.81 | .01 |
| AS | 6 | 23,216 | | |
| B (Criterion Range) | 3 | 32,645 | $<1$ | |
| BS | 18 | 116,081 | | |
| C (Direction of Flight) | 1 | 140,014 | $<1$ | |
| CS | 6 | 265,043 | | |
| AB | 3 | 9,619 | 1.05 | |
| ABS | 18 | 9,128 | | |
| AC | 1 | 355,051 | 19.07 | .01 |
| ACS | 6 | 18,623 | | |
| BC | 3 | 102,914 | 2.13 | |
| BCS | 18 | 48,232 | | |
| ABC | 3 | 131,854 | 6.46 | .01 |
| ABCS | 18 | 20,414 | | |

Table 6

**Mean Errors and Standard Deviations for Immediate Reinforcement Training (Posttests 2 and 3), Experiment III**

*(Meters)*

| Posttest | N | 400 Meters | | 800 Meters | | 1,500 Meters | | 2,500 Meters | |
|---|---|---|---|---|---|---|---|---|---|
| | | In | Out | In | Out | In | Out | In | Out |
| Posttest 2 | 7 | | | | | | | | |
| Mean Error | | -2 | +164 | +196 | +41 | +268 | -125 | +172 | -180 |
| SD | | 167 | 156 | 162 | 114 | 209 | 177 | 503 | 375 |
| DI | | 167 | 226 | 254 | 121 | 340 | 217 | 532 | 416 |
| Posttest 3 | 7 | | | | | | | | |
| Mean Error | | -64 | -30 | -24 | -26 | -43 | -7 | -114 | -14 |
| SD | | 115 | 126 | 175 | 165 | 284 | 194 | 415 | 358 |
| DI | | 132 | 130 | 177 | 167 | 287 | 194 | 430 | 358 |

means contributed to the three-way interaction. The significant differences that were meaningful in terms of the research objectives were related to changes in the magnitude of the incoming-outgoing bias as a function of criterion range and amount of training. For the 1,500-meter and 2,500-meter ranges, there were significant differences between incoming and outgoing errors at the end of Posttest 2, but not after Posttest 3; however, there were no significant changes in the errors for the 400-meter or 800-meter ranges. These interactions are graphed in Figure 14.

Aircraft Course and Altitude Analysis. The data used in the previous analysis for the immediate reinforcement group were re-sorted and analyzed for the effects of criterion range, course, and altitude, using a Lindquist Treatments X Subjects design. The analysis of variance summary is presented in

**Range Estimation Error as a Function of Amount of Training and Direction of Flight, Experiment III**

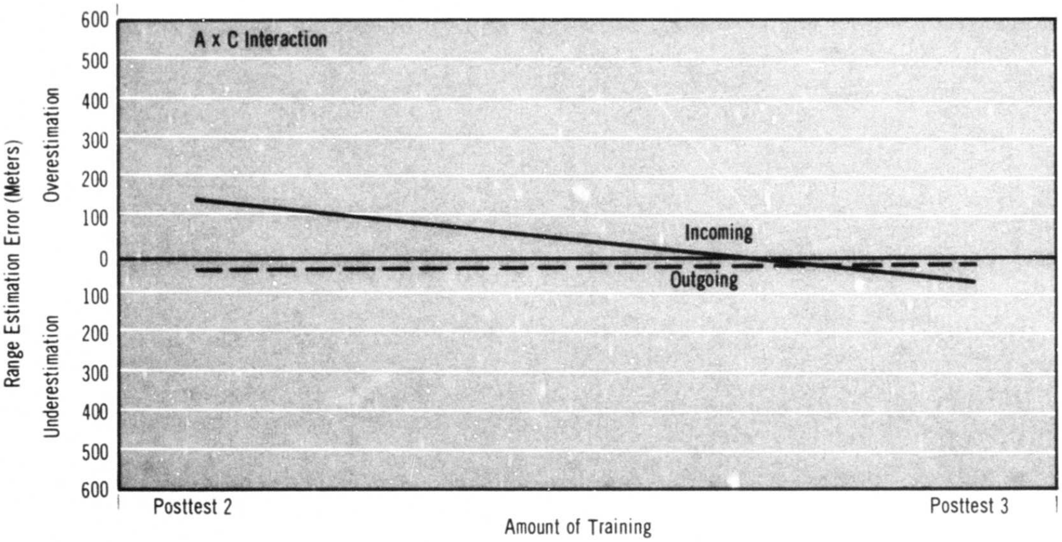


Figure 13

**Range Estimation Error as a Function of Amount of Training and Direction of Flight**

A x B x C Interaction

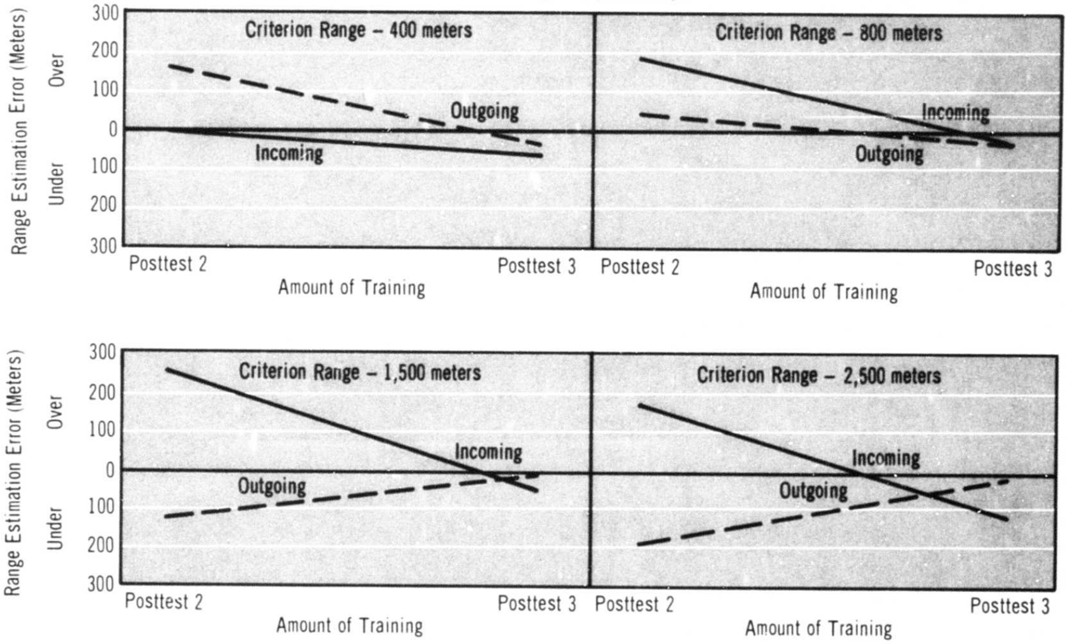


Figure 14

Table 7, and the mean errors and standard deviations for all experimental conditions are listed in Table 8.

The main effect for aircraft altitude was statistically significant at the .05 level. The mean error of +71 meters for high altitude flights was reduced to −34 meters for low altitude flights.

Two significant interactions were obtained in this analysis. Criterion range interacted with aircraft altitude at the .001 level, and the interaction among criterion range, aircraft course, and aircraft altitude was significant at the .05 level. Tukey's test revealed a large number of significant differences between pairs of means that contributed to the criterion-range by altitude interaction. The largest difference occurred

Table 7

**Analysis of Variance of Posttests 2 and 3 for Immediate Reinforcement Training, Experiment III: Criterion Range, Aircraft Course, Aircraft Altitude**

*(Mean Error in Meters)*

| Source of Variation | *df* | MS | *F* | *p* |
|---|---|---|---|---|
| S (Subjects) | 6 | | | |
| A (Criterion Range) | 3 | 253,115 | 2.04 | |
| AS | 18 | 123,861 | | |
| B (Aircraft Course) | 1 | 383,111 | 3.14 | |
| BS | 6 | 122,060 | | |
| C (Aircraft Altitude) | 1 | 315,110 | 9.61 | .05 |
| CS | 6 | 32,792 | | |
| AB | 3 | 175,976 | 2.84 | |
| ABS | 18 | 61,970 | | |
| AC | 3 | 149,067 | 12.74 | .001 |
| ACS | 18 | 11,703 | | |
| BC | 1 | 11,223 | $<1$ | |
| BCS | 6 | 113,788 | | |
| ABC | 3 | 338,348 | 3.26 | .05 |
| ABCS | 18 | 103,930 | | |

Table 8

**Mean Errors and Standard Deviations for Immediate Reinforcement Training, by Course and Altitude (Posttests 2 and 3), Experiment III**

*(Meters) (N=7)*

| Statistic | 400 Meters | | | | 800 Meters | | | | 1,500 Meters | | | | 2,500 Meters | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 200-Meter Offset | | Overhead | | 200-Meter Offset | | Overhead | | 200-Meter Offset | | Overhead | | 200-Meter Offset | | Overhead | | |
| | Low | High | Low | High | Low | High | Low | High | Low | High | Low | High | Low | High | Low | High | |
| Mean Error | +136 | +152 | −116 | +83 | +136 | +164 | −36 | −22 | −6 | +36 | −158 | +421 | −121 | +117 | −107 | −382 | +19 |
| SD | 244 | 155 | 97 | 110 | 157 | 152 | 162 | 60 | 211 | 309 | 158 | 190 | 619 | 346 | 523 | 313 | 331 |
| DI | 279 | 217 | 151 | 138 | 208 | 224 | 166 | 64 | 211 | 311 | 223 | 462 | 631 | 365 | 534 | 494 | 332 |

at the 1,500-meter range between high and low altitudes. This interaction is graphed in Figure 15.

Only one significant difference was found for the three-way interaction with Tukey's test, and it occurred between the 1,500-meter and 2,500-meter ranges for the high-altitude overhead courses. Since offset and altitudes were comparable, no satisfactory explanation of this interaction was possible.

**Range Estimation Error as a Function of Criterion Range and Aircraft Altitude, Experiment III**

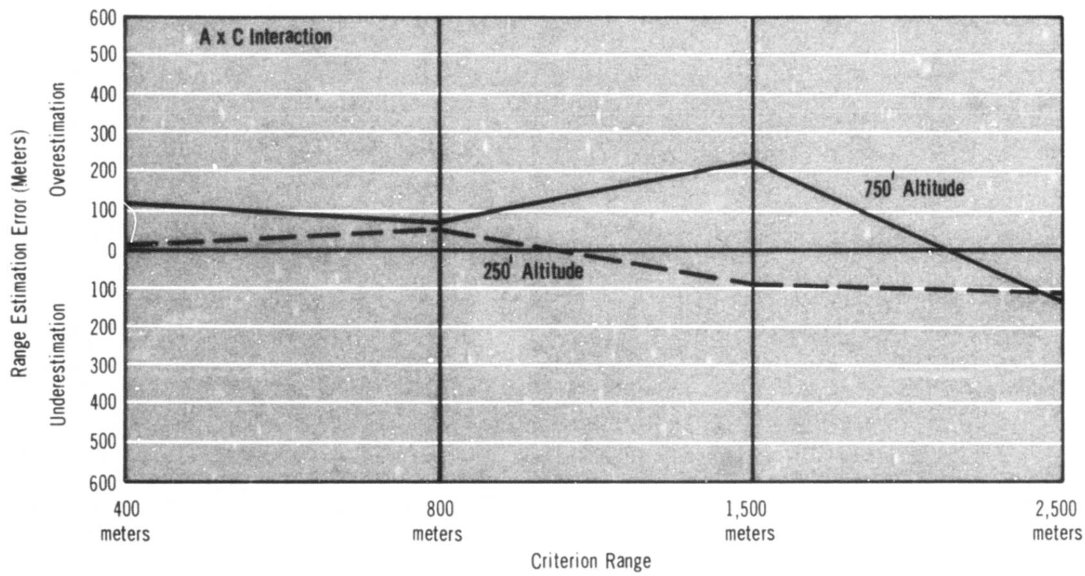


Figure 15

DISCUSSION

Training Methods. The primary objective of this study was to determine the most effective and efficient method of training observers to estimate the ranges of 400, 800, 1,500, and 2,500 meters.

In terms of accuracy of the judgments, the most effective range estimation training method was the immediate reinforcement method. The immediate reinforcement - helicopter group was next, followed by the two paired associate groups which were essentially equivalent. Since training method was not independent of range, some methods were more effective at certain ranges than others. The methods that were superior for each of the criterion ranges were as follows:

| Criterion Range | Training Method |
|---|---|
| 400 meters | Immediate Reinforcement, Immediate Reinforcement - Helicopter, Paired Associate - Helicopter |
| 800 meters | Immediate Reinforcement, Immediate Reinforcement - Helicopter, Paired Associate - Helicopter |
| 1,500 meters | Immediate Reinforcement, Paired Associate |
| 2,500 meters | Immediate Reinforcement |

The two helicopter groups were quite accurate in some cases at short range, but tended toward large errors of several hundred meters at the 1,500- and 2,500-meter ranges. In general, the immediate reinforcement - helicopter group overestimated the criterion ranges, and the paired associate - helicopter group underestimated them. These two groups represented the extremes of estimation error and the overall difference between them was found to be significant. Therefore, these methods were excluded as effective range estimation training methods.

With respect to variability, it was difficult to select the least variable training method since the relative superiority of the methods changed considerably with each criterion range. The immediate reinforcement - helicopter method and the paired associate method had the lowest standard deviations for the ranges of 400 and 800 meters, respectively. At the 1,500- and 2,500-meter ranges, the paired associate - helicopter method appeared to be the most effective in reducing variability.

Although the immediate reinforcement method was not the least variable one for some ranges, it was considered the most effective range estimation training method available because it produced the smallest average discrepancy of estimates about the criterion ranges as represented by the dispersion index.

Immediate Reinforcement Training. The reduction in range estimation errors between Posttests 2 and 3 was significant, indicating the necessity for the third day's training. The most dramatic improvements in performance as a result of additional training were reductions of the incoming-outgoing bias. At least a 79% reduction of the difference between incoming and outgoing estimates was observed for all criterion ranges, and up to a maximum reduction of 99% for the 800-meter range. In addition to reducing the directional bias, the standard deviations were considerably reduced in many instances by the third day's training. Therefore, it appears that at least 110 training trials are required to learn to estimate four criterion ranges. Also, it is not known whether the level of performance exhibited in the present investigation is asymptotic, and it may be that additional trials would be necessary to determine optimum performance.

The difference between aircraft altitudes of 250 feet and 750 feet had a significant effect on range estimation performance. The 1,500-meter criterion range was the only distance used which resulted in a significant difference between altitudes. Since this effect did not replicate for the other criterion ranges, an explanation based on aircraft aspect or visual angle could not be advanced.

It seems reasonable to expect that the variable of aircraft speed might have some effect on the incoming-outgoing bias. Within the experiments discussed up to this point, a few comparisons are possible. In Experiments I and II, a U-6A flew at a speed of 100 knots, and an F-100 maintained a speed of 400 knots for Experiment III. There were several discrepancies between the experimental conditions of these studies; however, to permit a comparison of aircraft speed, it will be assumed that the differences had negligible effects on range estimation performance. The following are mean range estimation errors for the 350- and 400-meter criterion ranges:

| Experiment | Aircraft | Incoming | Outgoing |
|---|---|---|---|
| I | U-6A | +145 meters | −48 meters |
| II | U-6A | +159 meters | −19 meters |
| III - Posttest 2 | F-100 | +159 meters | −100 meters |

Aircraft speed appears to have a differential effect on incoming and outgoing range estimation errors. As aircraft speed increased, the incoming errors of overestimation remained the same, but outgoing errors changed from slight underestimates to gross underestimation. As the aircraft approaches and passes crossover, speed becomes more apparent. The increase in outgoing underestimation with increasing speed may have been the result of attempts to anticipate the criterion ranges. By anticipating the criterion range, the observers may have expected to counteract the effects of aircraft speed.

The number of training trials administered to the subjects in Experiments I and II was equal to the amount received by the subjects in Experiment III at the time the second posttest was given. The results of Posttest 3 demonstrate that the incoming-outgoing bias may be further reduced with additional training. The overall mean error was reduced to −61 meters for the incoming flights and to −19 meters for the outgoing flights.

## Chapter 5

## THE EFFECTS OF REDUCED-SCALE PAIRED ASSOCIATE TRAINING ON RANGE ESTIMATION ERRORS IN A FULL-SCALE ENVIRONMENT (EXPERIMENT IV)

### PROBLEM

The purpose of this study was to determine the relative efficiency of reduced-scale vs. field range estimation training. This pilot study was conducted in conjunction with Experiment III to determine the potential of laboratory techniques of training range estimation.

### METHOD

The observers were three U.S. Army Air Defense Human Research Unit enlisted men (two of whom assisted in the survey of the test site for Experiment III) and three U.S. Army Air Defense Board enlisted men.

The reduced-scale training employed an equivalent of the paired associate method used in Experiment III. In the reduced-scale training a scale range and a scale model of an F-100 were used. The scale factor was 1:50. Observers were walked (not at scaled speed) to the scale range of interest, and told it was equivalent to $\chi$ meters range. A total of 36 training trials were used, and each trial consisted of announcing five ranges for the incoming direction and five ranges outgoing. These trials were identical to the paired associate trials received by the field observers in Experiment III.

The observers viewed the scale aircraft monocularly during all training trials. This was done to eliminate binocular cues for depth perception, which would have provided inappropriate and inaccurate information concerning aircraft range in the scaled situation. The reduced-scale training was conducted in a desert environment just north of El Paso. Total training time required was approximately four hours.

Due to instrumentation failures encountered in Experiment III, pretest data were not obtained, and only part of the desired posttest data was obtained. The field performance of the reduced-scale group was compared with the performance of the paired associate training groups from Experiment III. Both groups were tested concurrently under identical conditions in the Experiment III test environment.

### RESULTS

The means for the reduced-scale and full-scale paired associate training groups are plotted in Figure 16. Eight separate analyses of variance were computed for each combination of the four ranges of interest (400, 800, 1,500, and 2,500 meters) and inbound vs. outbound. The difference between the reduced-scale and full-scale training errors at the 1,500-meter distance on the inbound passes was the only difference found to be statistically reliable ($\underline{p} < .05$).

Plot of Range Estimate Means Reduced-Scale vs Full-Scale, Experiment IV

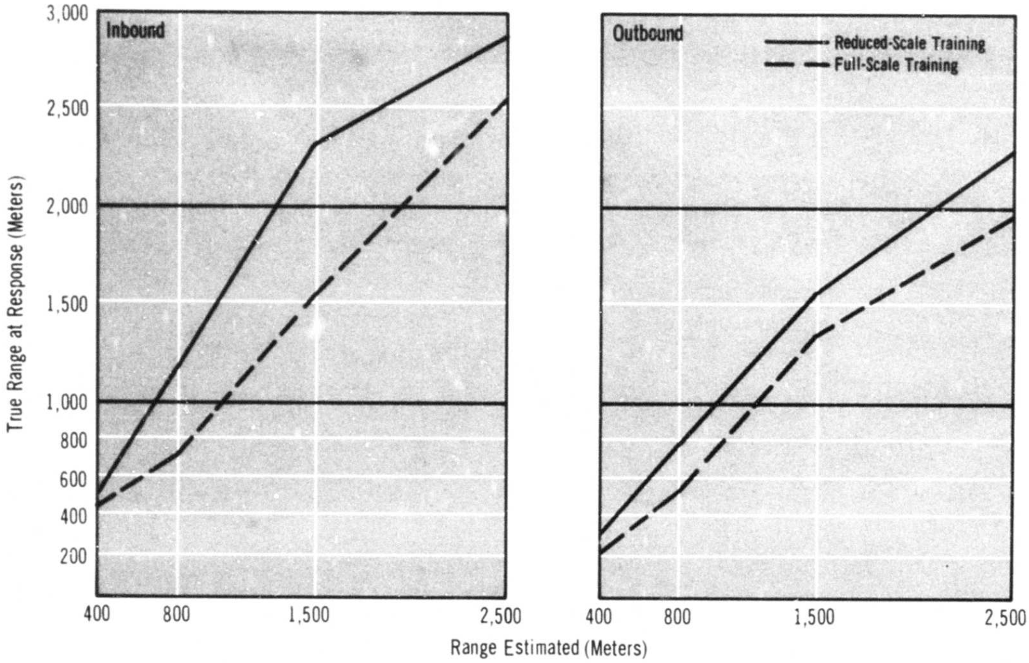


Figure 16

## DISCUSSION

Assuming the groups were equivalent before training, it appears that the reduced-scale training technique is as good as field training except for the 1,500-meter inbound estimate.

At this point some digression appears desirable. It had been noted by observers and test personnel in earlier tests that inbound aircraft appeared much closer than their true distance. Assuming this general belief was based on fact—that is, an illusion does exist—it appeared that the reduced-scale training was not eliminating this illusion. The paired associate training method, using real aircraft, would be expected to correct the illusion. The field data from Experiment III should, therefore, show the inbound illusion to diminish as training time increased. This effect did occur, and contributed to several significant interactions. The overall difference between incoming and outgoing estimates was reduced from 253 meters for Posttest 2 to 74 meters for Posttest 3. The additional training also resulted in further reduction of the illusion between posttests with increasing criterion range.

In any case, the present study indicated that scaled training techniques using model aircraft have potential in training range estimation. Scale training techniques must, however, provide more accurate inbound range estimates than obtained in this study to be considered an acceptable alternate to field range estimation training.

## Chapter 6

# THE EFFECTS OF REDUCED-SCALE IMMEDIATE REINFORCEMENT TRAINING ON RANGE ESTIMATION ERRORS IN A FULL-SCALE ENVIRONMENT (EXPERIMENT V)

## PROBLEM

The purpose of this study was to explore techniques of reduced-scale training that might provide acceptable inbound and outbound range estimation performance under field conditions. The basic assumption underlying the reduced-scale training techniques was that appropriate size-distance relationships that would transfer to field range estimation tasks were being trained. It was secondarily assumed that an illusion existed that caused inbound aircraft to appear closer than their true range. (Observers asked to respond when the aircraft is 800 meters distant tend to respond at a true range approaching 1,000-1,200 meters. This effect does not appear to exist for outbound aircraft.)

## METHOD

### Training Methods

Biased Training Method. Two training techniques were developed that were designed to correct the bias obtained on inbound estimates from Experiment IV. The first technique was simply to train the bias out; that is, teach the observers a biased size-distance relationship for inbound and the true size-distance relationship for outbound. The data obtained in Experiment IV were used to build an apparent size-distance scale for inbound aircraft. This training method will be referred to as the biased training method.

The biased method as tested in the present study is susceptible to at least two major faults: (a) The data from Experiment IV may not represent the appropriate training bias, and (b) aircraft speed or other characteristics may materially influence the magnitude of the bias. It cannot, therefore, be assumed that the correction employed would be appropriate for any conditions other than F-100s flying approximately 400 knots and under a similar desert terrain environment.

Aperture Training Method. The second training method assumed that the complex visual environment was contributing to overestimations of the criterion range on the inbound portion of the flight path, and relatively accurate judgments on the outbound portion of the flight path.

It was hypothesized that by reducing the complexity of the visual environment, providing a relatively constant comparison stimulus and emphasizing the size-distance relationship, the illusion could be reduced or eliminated.

A simple way of approaching these requirements was to have the observer view the aircraft through his partially closed fist. The observers were instructed to make a fist with about a dime-sized aperture at the far end of the fist, through which the aircraft would be observed. This reduced the amount of terrain in view, and provided a relatively stable comparison stimulus, that is, the dime-sized viewing aperture. This latter training will be referred to as the aperture training method.

## Procedure

Both groups were instructed to pay particular attention to the size of the aircraft (a 1:50 scale model) at the various distances, and to pick distinguishing features of the aircraft visible at those distances. Both groups viewed the model aircraft monocularly during training. Observers were initially walked through the scale training range and shown the aircraft at the scale (400, 800, 1,500, and 2,500 meters) ranges of interest. The range and aircraft were both 1:50 scale.

All training occurred in a sequence of inbound, then outbound. On inbound trials the observers walked toward a frontal view of the aircraft. On outbound trials, the observers backed away from a tail-on view of the aircraft. After the initial walk-through, the observers were asked to walk to the scaled 2,500-meter range. The observers were then moved to the 2,500-meter range and were asked to walk to the 1,500-meter range. One training trial was considered a walk-in and walk-out at each of the four ranges. Each trial, therefore, consisted of estimating each of the four ranges inbound and outbound and providing feedback at each of these ranges by moving to the correct range.

The correct range was measured by a series of coded knots tied in a small cord attached to the aircraft location and held by the experimenter. The knots corresponded to the ranges of interest and could be felt by the experimenter but not seen by the observers. Aircraft position was changed frequently to reduce the possibility of learning, or using, terrain features rather than aircraft size as an indicator of range. The two groups were trained simultaneously but separately, by locating them in opposite directions from the aircraft position.

The observers were given a pretest using the full-scale environment in conjunction with a replication of Experiment III. The observers were then given four training trials in a miniature training situation, tested in the Experiment III field environment, and given an additional 20 training trials and a second posttest in the Experiment III field environment.

## RESULTS AND DISCUSSION

The mean errors and standard deviations for all conditions of interest are presented in Table 9, and a summary of the analysis of variance in Table 10. The prime function of the analysis of variance in this study was to evaluate the training methods and their interactions with the remaining variables.

The two training methods employed were found to be significantly different ($p < .05$). The mean error was −14 meters for the aperture training group, and +127 meters for the biased training group. All three within-subject main effects were significant at the .001 level of confidence. The mean error of +175 meters for Posttest 1 was reduced to −62 meters for the second posttest, indicating further learning with additional training trials.

Range estimation errors for incoming passes were found to be significantly larger than those for the outgoing direction (+255 meters and −142 meters). The main effect for criterion range was significant due to the significant differences between the 2,500-meter range and the other three criterion ranges, as determined by Tukey's test. The mean range estimation errors for the 400-, 800-, 1,500-, and 2,500-meter ranges were +210, +191, +68, and −242, respectively.

Four first order interactions were significant: (a) amount-of-training by criterion-range, (b) training-methods by amount-of-training, (c) amount-of-training by direction-of-flight, and (d) criterion-range by direction-of-flight. The amount-of-training by criterion-range interaction indicated that the mean estimation error was reduced between Posttests 1 and 2 for all criterion ranges except the

Table 9

**Mean Errors and Standard Deviations for Posttests 1 and 2, Experiment V**

*(Meters)*

| Training Group | Posttest | N | 400 Meters | | 800 Meters | | 1,500 Meters | | 2,500 Meters | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | In | Out | In | Out | In | Out | In | Out | |
| Aperture Training | Posttest 1 | 8 | | | | | | | | | |
| | Mean Error | | +150 | +131 | +250 | +56 | +556 | −169 | +144 | −581 | +67 |
| | SD | | 71 | 166 | 156 | 270 | 486 | 309 | 390 | 320 | 430 |
| | DI | | 166 | 211 | 295 | 276 | 738 | 352 | 416 | 663 | 435 |
| | Posttest 2 | 8 | | | | | | | | | |
| | Mean Error | | +188 | +88 | +225 | −50 | +6 | −431 | −238 | −544 | −95 |
| | SD | | 167 | 78 | 184 | 192 | 174 | 123 | 228 | 233 | 320 |
| | DI | | 251 | 118 | 291 | 198 | 174 | 448 | 330 | 592 | 334 |
| Biased Training | Posttest 1 | 8 | | | | | | | | | |
| | Mean Error | | +456 | +206 | +613 | +44 | +875 | −94 | +288 | −119 | +284 |
| | SD | | 141 | 176 | 292 | 138 | 238 | 164 | 489 | 380 | 430 |
| | DI | | 477 | 271 | 679 | 145 | 907 | 189 | 568 | 398 | 515 |
| | Posttest 2 | 8 | | | | | | | | | |
| | Mean Error | | +338 | +125 | +431 | −38 | +138 | −338 | −331 | −556 | −29 |
| | SD | | 256 | 130 | 213 | 145 | 240 | 152 | 244 | 218 | 387 |
| | DI | | 424 | 180 | 481 | 150 | 277 | 371 | 411 | 597 | 388 |
| Total | Posttest 1 | 16 | | | | | | | | | |
| | Mean Error | | +303 | +169 | +432 | +50 | +716 | −132 | +216 | −350 | +176 |
| | SD | | 189 | 175 | 296 | 214 | 414 | 250 | 448 | 420 | 443 |
| | DI | | 357 | 243 | 524 | 220 | 827 | 283 | 497 | 547 | 477 |
| | Posttest 2 | 16 | | | | | | | | | |
| | Mean Error | | +263 | +107 | +328 | −44 | +72 | −385 | −285 | −550 | −62 |
| | SD | | 229 | 108 | 224 | 170 | 220 | 145 | 240 | 226 | 357 |
| | DI | | 349 | 152 | 397 | 176 | 231 | 411 | 373 | 595 | 362 |

2,500-meter range. Initial group differences or differential learning rates may have been indicated by the training-methods by amount-of-training interaction.

Range estimation errors for the biased training group for Posttest 1 were significantly larger than the other three training-methods by amount-of-training conditions. Inspection of the amount-of-training by direction-of-flight interaction indicated that incoming and outgoing errors were reduced with additional training.

The second order interaction of amount-of-training by criterion-range by direction-of-flight indicated that the difference between incoming and outgoing errors for each criterion range was reduced between Posttests 1 and 2. Inspection of the significant ($p < .05$) criterion-range by direction-of-flight interaction indicated that the magnitude of the difference between inbound and outbound errors tended to be a constant (approximately 500 meters) except for the 400-meter estimate where the inbound and outbound estimates tended to converge.

Inspection of the training-methods by criterion-range by direction-of-flight interaction indicated that the criterion-range by direction-of-flight interaction described performance for all but the aperture training group, which departed from this trend in that the 2,500-meter estimate was smaller than would have been predicted.

The analysis of variance was an interesting exercise, but it did not satisfactorily attack the basic question of adequacy of the training groups to estimate inbound and outbound ranges as a function of training.

Table 10

**Analysis of Variance of Posttests 1 and 2, Experiment V**
*(Mean Error in Meters)*

| Source of Variation | *df* | MS | *F* | *p* |
|---|---|---|---|---|
| Between *Ss* | 15 | 26,354 | <1 | |
| A (Training Methods) | 1 | 1,272,666 | 6.65 | .05 |
| Error A | 14 | 191,466 | | |
| Within *Ss* | 240 | 171,301 | | |
| B (Amount of Training) | 1 | 3,598,135 | 61.52 | .001 |
| AB | 1 | 363,760 | 6.39 | .05 |
| Error B | 14 | 58,491 | | |
| C (Criterion Range) | 3 | 2,797,978 | 24.31 | .001 |
| AC | 3 | 2,379 | <1 | |
| Error C | 42 | 115,104 | | |
| D (Direction of Flight) | 1 | 10,100,479 | 65.32 | .001 |
| AD | 1 | 157,510 | 1.02 | |
| Error D | 14 | 154,619 | | |
| BC | 3 | 592,327 | 19.89 | .001 |
| ABC | 3 | 75,712 | 2.54 | |
| Error BC | 42 | 29,779 | | |
| BD | 1 | 459,853 | 6.82 | .05 |
| ABD | 1 | 18,056 | <1 | |
| Error BD | 14 | 67,437 | | |
| CD | 3 | 687,535 | 21.14 | .001 |
| ACD | 3 | 174,410 | 5.36 | .01 |
| Error CD | 42 | 32,520 | | |
| BCD | 3 | 170,921 | 5.11 | .01 |
| ABCD | 3 | 42,614 | 1.27 | |
| Error BCD | 42 | 33,434 | | |

Table 11 presents the percentage of range estimates that were within plus or minus approximately 10, 25, and 50% of the ranges being estimated. From this analysis, it was apparent that learning occurred and that range estimates after training were superior to estimates before training.

Experiment V indicated that observers can be trained to estimate aircraft range without using live aircraft in the training.

Table 11

**Percent of Estimates Within Approximately ±10, ±25, ±50 Percent of Range Being Estimated, Experiment V**

| Error Magnitude | Biased Training | | | Aperture | | |
|---|---|---|---|---|---|---|
| | Pretest | First Posttest | Second Posttest | Pretest | First Posttest | Second Posttest |
| Inbound | | | | | | |
| ±10 | 3.1 | 13.5 | 19.8 | 6.2 | 21.9 | 40.6 |
| ±25 | 10.4 | 21.9 | 57.3 | 20.8 | 52.1 | 65.6 |
| ±50 | 19.8 | 41.7 | 71.9 | 31.2 | 80.2 | 84.4 |
| Outbound | | | | | | |
| ±10 | 6.2 | 39.6 | 26.0 | 15.6 | 31.2 | 26.0 |
| ±25 | 12.5 | 74.0 | 61.5 | 33.3 | 52.1 | 58.3 |
| ±50 | 35.4 | 86.5 | 91.7 | 53.1 | 85.4 | 90.6 |

## Chapter 7

# THE EFFECTS OF REDUCED-SCALE OCCLUSION TRAINING ON RANGE ESTIMATION ERRORS IN A REDUCED-SCALE ENVIRONMENT

## (EXPERIMENT VI)

### PROBLEM

The purpose of this study was to determine the number of training trials required for observers to learn to estimate a scale distance of 350 meters using the occlusion method of range estimation training. Attempts were made to reduce estimation errors in a scaled-down environment using the M-14 rifle front sight guards as an occluding job aid. After training with one aircraft type, the extent to which training would transfer to other aircraft types was also determined.

### METHOD

Subjects. The subjects consisted of six U.S. Army Air Defense Human Research Unit enlisted men and two research personnel.

Miniature Range. An indoor miniature range of 1/72nd scale was constructed to provide the appropriate stimuli for the investigation. An aircraft model of 1/72nd scale was mounted on the carriage base of the range, which was approximately 25 feet long. The carriage was electrically powered and was capable of simulating speeds up to 180 knots. Responses were made with a commercially available BB gun that was modified to meet the requirements of the study. The gun was provided with an M-14 rifle sight, and a switch was attached to the trigger, which stopped the moving target.

Training Procedure. The trainees were instructed in the use of the M-14 rifle sight as an aid in range estimation. Diagrams were used to illustrate the approximate relationship between the target aircraft and range estimation aid. The subjects were then trained to use the M-14 rifle sight to estimate a 350-meter distance. A 1/72nd-scale F-4 aircraft moving at a scale speed representing 100 knots was used as the target. Scaled distances were used to represent 0-, 100-, 200-, and 300-meter observer offsets from the target's path. This required the trainees to learn the correct sight picture for all aspects of the aircraft.

The trainees then practiced using the aid by making an estimation that was followed immediately with knowledge of results. Specifically, the trainee observed the target moving slowly toward (or away from) his position. As soon as he believed that the target was at the scaled distance representing 350 meters, he stopped the target. A check was made to determine how close his estimate was to 350 meters. If the estimate was in error, the target was moved to the correct position to provide feedback information to the trainee.

The trainees were positioned at several locations for each offset distance to generalize the training and reduce extraneous cues. Additional cues were eliminated by covering the background areas with target cloth. Each subject continued making estimates until he had four consecutive trials with no more than a 10% error. The first five estimates were recorded as pretest scores, and no knowledge of results followed these trials. Immediately after the training criterion had been met, a five-trial posttest was given.

Transfer of Training. After the eight subjects had been trained, they were used in a study evaluating the generalization and transfer of training to various offsets and various aircraft. The dimensions of the actual aircraft vary according to the following statistics:

| Jet Aircraft | N | Mean (feet) | SD (feet) |
|---|---|---|---|
| Fuselage Length | 27 | 48 | 8.7 |
| Wing Span | 27 | 35 | 7.9 |
| Propeller Aircraft | | | |
| Fuselage Length | 14 | 34 | 7.0 |
| Wing Span | 14 | 45 | 8.2 |

Because of this variation, there is a question of how useful range estimation aids are when used with one general rule. The study determined the error in estimating 350 meters as a function of four aircraft size variations and four different offsets.

The aircraft that were used, and their full scale dimensions in feet are:

| Aircraft | Fuselage | Wing Span |
|---|---|---|
| F-4 | 56 | 38 |
| F-104 | 55 | 22 |
| Mig 19 | 36 | 32 |
| Mig 21 | 40 | 28 |

The offsets used were 0 (overhead course), 100, 200, and 300 meters. These cover the approximate range of offsets that would allow the M-14 rifle to be fired at aerial targets.

## RESULTS

During training with the F-4, the mean error of estimation began to stabilize after 10 trials at 14% error or less. Since the trainees were required to estimate 350 meters to all aspects of the aircraft, this training level is comparable to previous range estimation studies. In order to determine how well the training generalized in estimating the range of 350 meters for other aircraft, each trainee was tested with the four aircraft. The distance was estimated to the aircraft from all four offsets. The mean errors and standard deviations for all experimental conditions are presented in Table 12.

The data for the posttest including all four aircraft were analyzed in a Lindquist Treatments X Subjects design. The variables examined were direction of flight, offset, and aircraft size. Table 13 presents a summary of the analysis of variance.

The analysis revealed two significant main effects—direction of flight and offset. Outgoing range estimation errors were found to be significantly larger than incoming errors (+1 and −25 meters, $p < .001$). There were also significant differences in range estimation performance as a function of offset. The mean errors for the 0-, 100-, 200-, and 300-meter offsets were −37, −28, −14, and +31 meters, respectively.

Table 12

**Mean Errors and Standard Deviations for All Treatment Conditions, Experiment VI**
*(Meters)*

| Aircraft | $N$ | Incoming | | | | Outgoing | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 Meters | 100 Meters | 200 Meters | 300 Meters | 0 Meters | 100 Meters | 200 Meters | 300 Meters | |
| F-4 | 8 | | | | | | | | | |
| Mean Error | | −24 | +17 | −2 | +32 | −26 | −37 | −15 | +34 | −3 |
| SD | | 27 | 35 | 42 | 30 | 54 | 42 | 34 | 36 | 46 |
| DI | | 36 | 39 | 42 | 44 | 60 | 56 | 37 | 50 | 46 |
| F-104 | 8 | | | | | | | | | |
| Mean Error | | −12 | −17 | −13 | +36 | −82 | −48 | −28 | +38 | −16 |
| SD | | 25 | 50 | 36 | 24 | 55 | 36 | 57 | 30 | 55 |
| DI | | 28 | 53 | 38 | 43 | 99 | 60 | 64 | 48 | 57 |
| M-19 | 8 | | | | | | | | | |
| Mean Error | | +4 | −11 | −11 | +19 | −33 | −61 | −7 | +19 | −10 |
| SD | | 38 | 42 | 18 | 20 | 35 | 50 | 45 | 16 | 42 |
| DI | | 38 | 43 | 21 | 28 | 48 | 79 | 46 | 25 | 43 |
| M-21 | 8 | | | | | | | | | |
| Mean Error | | −51 | −3 | +1 | +50 | −72 | −67 | −36 | +18 | −20 |
| SD | | 31 | 41 | 41 | 25 | 35 | 17 | 32 | 23 | 51 |
| DI | | 60 | 41 | 41 | 56 | 80 | 69 | 48 | 29 | 55 |
| Total | 32 | | | | | | | | | |
| Mean Error | | −21 | −4 | −6 | +34 | −53 | −53 | −22 | +27 | −12 |
| SD | | 37 | 44 | 36 | 28 | 52 | 40 | 42 | 29 | 49 |
| DI | | 43 | 44 | 37 | 44 | 74 | 66 | 47 | 40 | 50 |

Table 13

**Analysis of Variance of Range Estimation Errors, Experiment VI**

| Source of Variation | $df$ | MS | $F$ | $p$ |
|---|---|---|---|---|
| S (Subjects) | 7 | 5,313 | | |
| A (Direction of Flight) | 1 | 43,786 | 30.47 | .001 |
| AS | 7 | 1,437 | | |
| B (Observer Offset) | 3 | 57,965 | 22.43 | .001 |
| BS | 21 | 2,584 | | |
| C (Aircraft Type) | 3 | 3,586 | 2.30 | |
| CS | 21 | 1,557 | | |
| AB | 3 | 5,916 | 6.02 | .01 |
| ABS | 21 | 982 | | |
| AC | 3 | 1,413 | $<1$ | |
| ACS | 21 | 1,615 | | |
| BC | 9 | 2,578 | 2.26 | .05 |
| BCS | 63 | 1,142 | | |
| ABC | 9 | 1,606 | 1.35 | |
| ABCS | 63 | 1,193 | | |

The direction-of-flight by offset and the offset by aircraft were the only significant interactions. The direction-of-flight by offset interaction indicated an increasing reduction of the incoming-outgoing bias with increasing offset.

The difference between incoming and outgoing range estimation errors for the 0-, 100-, 200-, and 300-meter offsets were 34, 50, 15, and 7 meters, respectively.

The interaction of aircraft size and offset was found to be significant at the .05 level. In general, the effects of aircraft size tended to decrease as offset increased. The differences between aircraft were greater at the 0- and 100-meter offsets than for the 200- and 300-meter offsets. These interactions are represented graphically in Figures 17 and 18.

**Range Estimation Error as a Function of Direction of Flight and Observer Offset, Experiment VI**

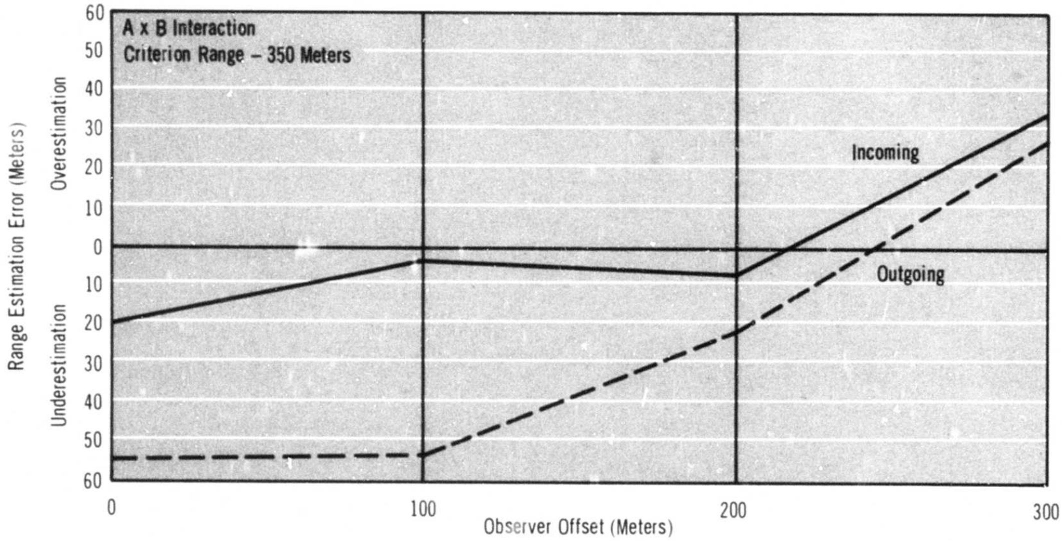


Figure 17

**Range Estimation Error as a Function of Observer Offset and Aircraft Type, Experiment VI**

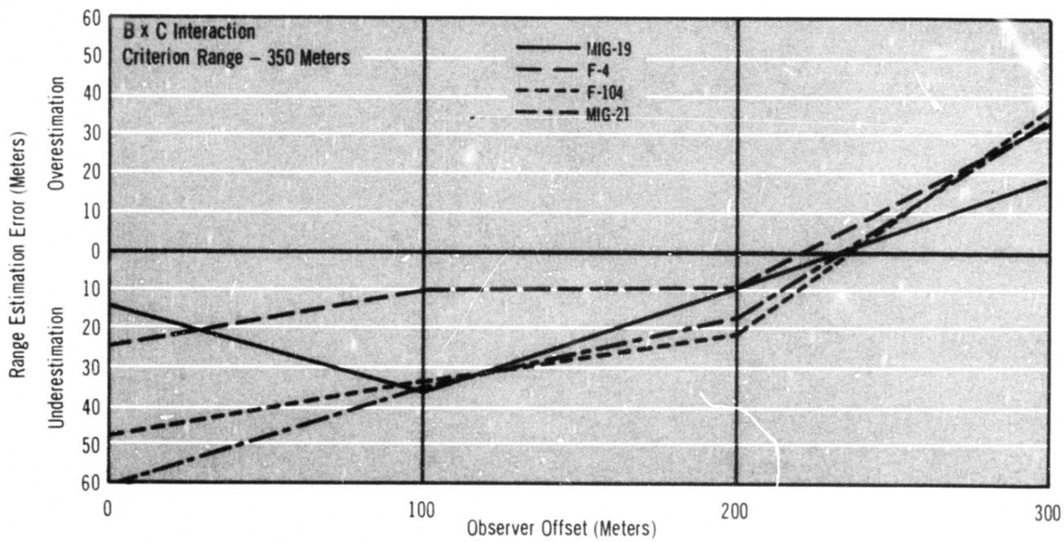


Figure 18

## DISCUSSION

Although the difference between incoming and outgoing estimates was significant in this study, the incoming judgments were considerably more accurate than those observed in field performance.

In the miniature range situation it was possible to establish two anchor points, a room wall behind the incoming flights and crossover for the outgoing direction. The increased accuracy of incoming judgments may have been due to factors unique to the scaled environment or the establishment of an incoming anchor. The underestimation of outgoing judgments noted in the present study may have been caused by differences in aircraft aspect. For the nearly overhead offsets, the outgoing aircraft may have had an apparently smaller size, resulting in underestimation of the criterion range. If the tail view of an aircraft produced apparently smaller size, the incoming-outgoing bias should be reduced with increasing offset. This reduction did occur, but aircraft aspect and angular velocity were confounded with offset. The reduction of bias with increasing offset could be attributed to either changing aircraft aspect or decreasing angular velocity.

An increase in aircraft offset appears to improve range estimation performance up to a certain point. It could be predicted that the optimum performance for estimating 350 meters would occur somewhere between the 200- and 300-meter offset. The judgments tended to be underestimates for the first three offsets, changing to overestimates for the 300-meter offset. The standard deviations tended to be the lowest at the 300-meter offset, but the decrease in variability with increasing offset was not linear, since the largest standard deviations were observed at the 100- and 200-meter offsets.

The range estimation performance observed in this miniature situation differed from field performance in two respects. The incoming judgments were extremely accurate, whereas field performance has been generally characterized by gross overestimation for the incoming direction of flight. Second, the magnitude of mean error and standard deviation was much smaller in the scaled environment.

## Chapter 8

## DISCUSSION AND CONCLUSIONS

### SUMMATION

The first two experiments described in this report were intended to provide guidelines for future research on SKYFIRE Sub-Unit I. Experiments III and VI were conducted to satisfy consulting requests from the Army and Experiments IV and V were feasibility studies. The primary purpose of all the studies was to provide initial data on range estimation training methods and variables which influence performance.

In addition to collecting preliminary range estimation data, considerable experience was gained in field research methods. Since the research methodology was continually being developed, it was believed that all the studies contained unknown and differing amounts of measurement error. Three potential sources of measurement error may have been present: (a) survey of ground distances, (b) methods of obtaining aircraft position data, and (c) ability of the pilot to accurately fly the assigned courses, altitudes, and speeds.

If these errors did occur, they would have produced inaccurate aircraft range data that were used for training and testing range estimation skills. As a result, the data collected in Experiments I through V should be regarded with caution. Since all the observers for each experiment were making range estimates simultaneously, the errors produced would tend to be systematic rather than random. Therefore, the relative relationship between variables and the difference in error between levels of a variable should be useful to indicate influential variables, but statements involving the magnitude of the estimation error should be regarded with caution.

Although these studies were preliminary in nature and subject to several potential sources of measurement error, a few tentative conclusions are possible. It was quite apparent in all studies that range estimation performance was improved with training. The effects of training tended to reduce the mean error of estimation, reduce variability, and partially or completely eliminate constant errors of estimation.

These results were found with several training methods, but some tended to be more effective than others. For short ranges, the finger occlusion method yielded the best results. The occlusion method was also less susceptible to certain influencing factors such as the incoming-outgoing bias. When longer ranges were involved and range estimation aids were not available, immediate reinforcement training appeared to be the best method.

If observers are to be trained to estimate one range, a minimum of 20 training trials appears to be required for satisfactory performance. When training a single group of observers to estimate four ranges, an average of at least 110 trials should be administered to obtain an equivalent level of performance. It is not known whether the resulting levels of performance represent the maximum attainable. Also, the retention characteristics of the training methods have not been examined. The time periods involved in the present studies required persistence of training effects for only short time intervals.

One factor that tended to influence range estimation performance was aircraft elevation. This variable appeared to increase the apparent size of aircraft flying at low elevation, resulting in overestimation of range. The elevation effect was considerably reduced with training, and was subject to a certain amount of control. By blocking the terrain from view, the effects of low target elevation were reduced, which increased the accuracy of range estimates.

All of the present studies have demonstrated a consistent difference between incoming and outgoing judgments. Incoming judgments were generally large overestimations of range and outgoing judgments were relatively accurate. Low aircraft elevation appeared to be a contributor to the incoming overestimations. The establishment of an "anchor" for distance estimation at crossover may account for the increased accuracy and reduced variability observed for outgoing judgments. The incoming-outgoing bias might also be explained in terms of aircraft aspect, aircraft speed, or first vs. second response, but all of these variables have been shown to merit further study. Regardless of the explanation, range estimation training significantly reduces the incoming-outgoing bias.

Other variables that were shown to affect range estimation performance were aircraft course, altitude, and crossing range. Further research with these factors should assist in defining the constant errors of range estimation performance.

Range estimation training methods using model aircraft appear to have a great deal of potential. These methods have resulted in significant improvements in performance, and significant reductions of the incoming-outgoing bias. At the present time, however, an adequate validation test with a carefully controlled field study has not been conducted.

## IMPLICATIONS FOR SYSTEM EFFECTIVENESS

The need for research on range estimation ability is justified on the assumption that increasing the accuracy of range estimation should result in an increase in the likelihood of obtaining hits on an aircraft. In addition, accurate range estimates should also reduce the number of rounds fired when an aircraft is beyond the effective range of the weapon.

In the case of weapons with a low rate of fire, the number of rounds saved by withholding fire until the aircraft is within range may be of only academic interest. However, in the case of single-shot AD missile engagements or automatic weapons with an extremely high rate of fire, the desire to have a high engagement likelihood with minimum expenditure of ordnance (ammunition) may be of critical importance, particularly when a commander is concerned with maximizing his weapon system effectiveness over successive engagements (that is, time). If rounds are fired when an aircraft is beyond effective range, the likelihood that the aircraft will be hit will be low, and, of possible equal tactical significance, those ineffectively fired rounds will not be available for subsequent engagement.

The effect of range estimation training on system effectiveness may be illustrated by using the pre-training and post-training range estimation data obtained in Experiment V, one of the miniaturization studies. The cumulative percentage of the range estimates given in the field test situation before and after training are shown in Figures 19 and 20. These data will be used to

Pretest Cumulative Percent Response

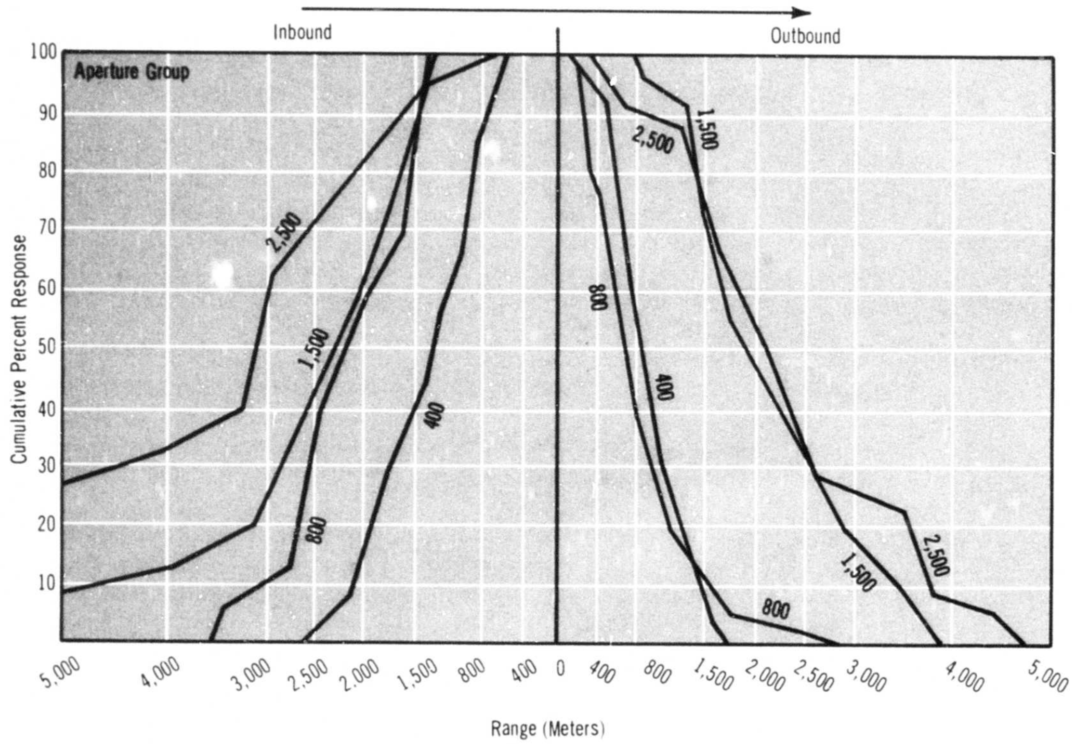


Figure 19

illustrate the effect of range estimation training on the effectiveness of a hypothetical weapon system.

The hypothetical weapon system consists of a visually aimed, single-shot missile system. It has a hit probability of .200 if missile launch occurs when the aircraft is within 2,500 meters of the gunner and a hit probability of .001 if the missile is launched when the aircraft is beyond 2,500 meters. For illustrative purposes, the example is concerned only with engagements of outbound aircraft.

From Figure 19 it can be seen that before training, approximately 35% of the judgments of 2,500 meters (the right hand curve) would actually have occurred when the aircraft was beyond the effective range. The overall system effectiveness per 100 attempted engagements would be equal to $65(.200) + 35(.001) = 13.03$ hits.

From the data in Figure 20, after training, only 5% of the estimates of 2,500 meters would occur when the aircraft was beyond that distance. In this case, per 100 attempted engagements, the following system effectiveness would occur: $95(.200) + 5(.001) = 19.005$ hits. Disregarding the fractional hits, the range estimation training would have resulted in a 46% increase in system effectiveness: $100(19-13 \div 13) = 46\%$.

It is probably doubtful that such dramatic increases in system effectiveness could be achieved in the real world by only providing range estimation training for the hypothetical weapon system. This illustration does, however, reveal that increased accuracy in range estimation judgments could result in more than a quantum increase in system effectiveness.

Posttest Cumulative Percent Response

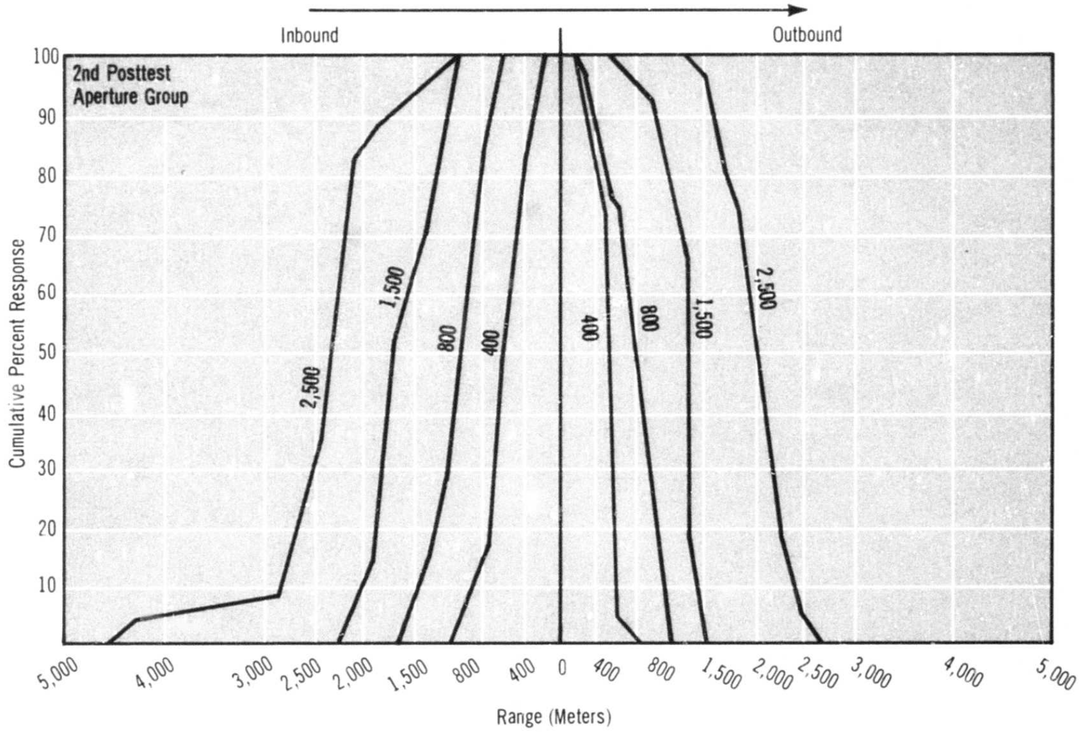


Figure 20

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## Appendix

# METHODS OF OBTAINING AIRCRAFT POSITION DATA

### Experiments I and II

The aircraft range information used for training and testing purposes was based on several assumptions: (a) that the azimuth location device constituted a simple and effective means of obtaining accurate aircraft position data; (b) that the pilot was correctly flying the assigned courses, altitudes, and speeds; and (c) that ground distances had been correctly surveyed.

The azimuth location device sketched in Figure A-1 was the basic apparatus used for Experiments I through V.

After the assumptions listed above were made, the azimuth positions from the range assistant location were computed in advance for each of the slant ranges. The range pegs, placed at the computed azimuth positions, corresponded to specific slant ranges between the aircraft and test control. When the range assistant was sighting through the eye cup, slant ranges were assumed to be equivalent to the coincidence of the aircraft with one of the range pegs. The alignment peg was used to locate the eye cup on a line perpendicular to the aircraft flight paths which also placed the range pegs parallel to them.

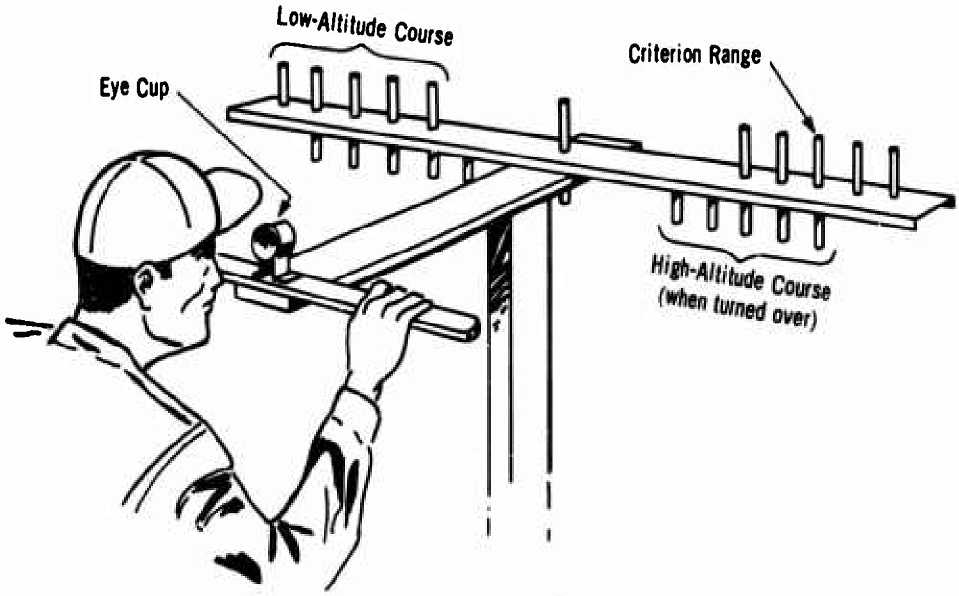
To obtain any specific slant range, the range assistant positioned his eye in the eye cup and waited for the nose of the aircraft to touch the corresponding range peg. He then transmitted verbally or electrically the given slant range. For the training trials, the range assistant verbally relayed five incoming and five outgoing ranges to the instructor over field phones. During the test trials, the range assistant electrically relayed the incoming and outgoing criterion ranges to one of the event recorder channels.

For each study, a series of different azimuth devices were required. A separate device had to be constructed for each combination of aircraft course and altitude, since changes in these variables resulted in different azimuth positions for the same series of ranges.

### Experiment III

Aircraft position data for this study were obtained in the same manner as described above, and only slight variations in the construction of the devices were necessary to accommodate different courses and altitudes. The primary difference between studies was the method of transmitting range information. A communication link between test control and the four range assistant positions was created by using a five-watt citizens band base station and four one-watt transceivers. The training ranges were relayed verbally as before but the correct slant ranges for test trials were entered on each of two event recorders by modifying the citizens band equipment to transmit a pulsed signal. All the transceivers were capable of generating an audio signal which was manually triggered by the range assistants. The signal was received by the base station which, in turn, tripped one channel on each event recorder.

**Azimuth Location Device**



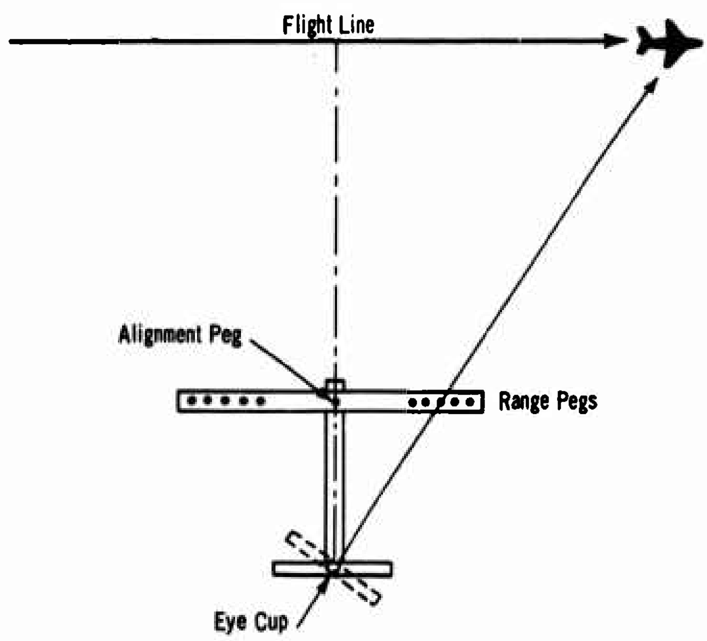




Figure A-1

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13. ABSTRACT

Six pilot studies were conducted to determine the effects of training on range estimation performance for aerial targets, and to identify some of the relevant variables. Observers were trained to estimate ranges of 350, 400, 800, 1,500, or 2,500 meters. Several variations of range estimation training methods were studied, including immediate knowledge of results after making an estimation, "paired associate" presentation of observed aircraft position with actual range information, and the use of an occluding object as a range estimation aid. Two variables that tended to influence performance were aircraft elevation and incoming-outgoing directions of flight.

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| Forward Area Weapons | | | | | | |
| Miniaturization | | | | | | |
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